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STEALTH:

AN EXAMPLE OF TECHNOLOGY'S ROLE

IN THE AMERICAN WAY OF WAR

by

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Abstract

This paper traces the development of stealth as an example of the way in which technology is invented, selected, acquired, and employed by the U.S. Armed Forces. The relationship between technology and the American culture that uses it is the foundation of the discussion. Stealth, as a specific technology, is traced from the prominent position of technology in the American way of war through its employment on the battlefield in Operation DESERT STORM. Lessons from this development highlight the different levels of success achieved by the American way of war as contrasted to the American way of acquisition. Finally, doctrine technology application, future opportunities, and limitations are explored in an effort to flesh out a comprehensive view of how the development of stealth contributed to the American way of war and what lessons can be applied to the key supporting element, the American way of acquisition. The apparent effectiveness of the application of stealth technologies should not imply that the same level of success was achieved in the acquisition of those technologies. The seemingly unplanned convergence of basic research, a well understood requirement, a number of supporting technologies, and the right entrepreneur is compared to a robust application of stealth technology to combat through the medium of doctrine. The author concludes that doctrine does not have the same effect on the technology process selection as it has on its application and that the importance of the human element to technology development has not diminished, but continues to grow.

Biographical Sketch

NEIL G. KACENA

COLONEL, U.S. AIR FORCE

Colonel Neil G. Kacena is a native of Cedar Rapids, Iowa, and received his bachelors degree from Iowa State University in 1973, and his masters degree from Troy State University in 1978. He was commissioned as a second lieutenant through the Reserve Officers Training Corps in 1973, and completed pilot training at Columbus Air Force Base, Mississippi, in 1974.

Col Kacena's first assignment after completing F-4 Replacement Training Unit at Luke Air force Base was as an F-4 aircraft commander at Udorn Royal Thai Air Base in 1975. After returning to the States, he was assigned as an F-15 pilot to the 1st Tactical Fighter Wing at Langley Air Force Base, Virginia, in 1976, he transferred to the 36th Tactical Fighter Wing and was assigned to the 525 Tactical Fighter Squadron at Bitburg Air Base, Germany in 1977, where he served as the Chief of Wing Scheduling and as a F-15 Instructor Pilot. Returning again to the States in 1980, he graduated from the F-15 Fighter Weapons Instructor Course at Nellis Air Force Base, Nevada, enroute to Weapons Officer and Flight Commander duties at the 555 Tactical Fighter Training Squadron, Luke Air Force Base, Arizona. In 1983, Col Kacena moved to Nellis Air Force Base, Nevada, as a USAF Fighter Weapons Instructor Course Instructor. After attending the USAF Air Command and Staff College, at Maxwell Air Force Base, Alabama, in 1987, he was assigned to the Assistant Secretary of the Air Force, Directorate of Special Programs as the Tactical Branch Chief and later as the Deputy Division Chief. In 1990, he was reassigned to the 49th Fighter Wing, Holloman Air Force Base, New Mexico, where he assumed the positions of Operations Officer and then Commander, 9th Fighter Squadron. After completing a command tour with the Iron Knights, Col Kacena was reassigned to the U.S. Central Command as the Chief, U.S. Liaison Office Doha, Qatar. Col Kacena graduated from the Armed Forces Staff College, Norfolk, Virginia in 1993 and is currently attending the U.S.A.F. Air War College at Maxwell Air Force Base, Alabama.

His decorations and awards include the Defense Superior Service Medal, the Air Force Meritorious Service Medal, the Air Force Aerial Achievement Medal, and the Air Force Commendation Medal. He was selected as Tactical Air Command's Instructor of the Year, 1983. Col Kacena has over 2,700 hours of fighter time including 2,400 hours in the F-15.

He is married to the former Jennifer J. Ramsay of Cedar Rapids, Iowa and has two sons, Mark and Drew.

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CHAPTER 1 -- Introduction

The success of U.S. military forces in the Gulf War focused the world's attention on how technology could affect the outcome of a conflict. Of all of the technologies of war displayed on the nightly news, the F-117 ended up on center stage. More than anything else, its effectiveness was based on the application of stealth technologies. Technology has become a pervasive part of America's culture and as such has imbedded itself into the fabric of the American military machine. It is, at the same time, an inseparable and problematic heart of the American way of war. Although the importance of technology is paramount to the application of U.S. military power, the process by which we invent, select, acquire, and employ it lacks the systematic approach that would be expected for such a key contributor to the very survival of the state. The inadequacy of this process, or what might be called "non-process," to support the underlying doctrine in an efficient and systematic fashion is the crux of the problem.

The story of the development of stealth technologies is an example of this "non-process" and illustrates both the randomness as well as the potential success of the system. The selection, development, and application of stealth technologies probably tells us more about the real world process of technology acquisition than the formal process. The acquisition process, although occasionally successful in giving birth to a breakthrough technology, is characterized by the inconsistent and random way in which technologies are selected for development. The development of stealth is an example of a product of the technology acquisition system, albeit a successful one, but also much more. Its development fosters insight to the relationship between culture, technology, principles of warfare, doctrine, and success in warfare. The complex links between each of the preceding areas cannot be fully explored in this paper, but the relevant facets

of the story will be examined in enough detail to explore the relationships of each to the other, always with the focus on the group of technologies called stealth.

Stealth. What is it? How was it developed and applied? What process was used? How should stealth derived technologies be utilized? These and many other questions surround the term stealth. The emergence of stealth technology illustrates the following system characteristics: current spurious technology selection process; applied uses; doctrinal development; quality vs. quantity debate; and counterstealth efforts. The history of the application of technology in warfare provides valuable lessons in this regard. This paper uses a review of multiple components of the development of stealth technology, which illustrates the pitfalls of the current technology development system, to build a conceptual foundation for the future expansion of stealth applications, doctrine, and counterstealth capabilities. This cannot be accomplished without an initial focus on stealth itself. Key to this understanding is the fact that stealth has many attributes, but derives its importance from radar. Radar is the dominant battlefield technology which has been so completely distributed itself throughout the five critical war related technologies: delivery, intelligence, payload, protective, and production.[1] Although stealth technology involves much more than counter radar capabilities, the predominant area of focus is correctly on radar. Throughout the history of warfare, adversaries have developed counters to newly fielded technologies. The development of stealth to counter radar guided weapons is an example of this classic competition.

Under ideal circumstances, warfighters perceive the need for a new tactic, weapon, or combination of the two, to fulfill a mission requirement. Stealth did not follow this classical pattern. Rather, the mission need that eventually motivated the development of stealth had

already been well defined and initially satisfied using the classic pattern format. The selection of stealth, as an alternate solution to the highly developed force packaging approach, represents the spurious way by which technologies are currently selected for development. The term stealth, a catchy phrase that the media enjoys, entered current use as a descriptor of the characteristics of the F-117 and has not been well understood ever since.[2] Although this use of the term is contemporary, the concepts that are associated with the term have been around as long as the principles of war have been identified as a desirable objective in warfare.

By first understanding the dominate nature of technology in the American way of war, the development of stealth can be reviewed in the context in which it was conceived, that is under the American technology development system. The inescapable conclusion is that the American way of technology development has not achieved the high levels of success associated with the American way of war. The success of the American way of war is simply not repeated in the technology development process that supports it. The organization of this proposition relies on a basic understanding of the definition of stealth and the fundamentals behind it. By outlining the motivation behind the development of stealth and the technological development itself, the lack of a focused technology development approach will be highlighted. The successful results of stealth's employment, and the doctrine supporting it, tend to mitigate the problems associated with the development system that supports it. Both the problems and the impact of future developments will be addressed in order to consolidate an understanding of the simultaneous inadequacy of the U.S. technology development system and the apparent success associated with the doctrine guided application of technology to the American way of war. The development of stealth provides a vehicle that illustrates both. Although this paper centers on stealth, it is only an

example. The lessons learned apply across the technology development system and its contribution to the American way of war.

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[1] Ralph Sanders, "Three Dimensional Warfare: World War II," *Technology In Western Civilization*, ed by Melvin Kranzberg and Carroll W. Pursell, Jr., (Oxford University Press, New York, 1967), p 564.
[2] Stewart Cranston, BGen (S), USAF, "Challenges of a Maturing Revolution," Speech delivered at the MIT/Lincoln Labs sponsored Cruise Missile Workshop, 1 May 1990.

CHAPTER 2 -- Background

Any discussion of a specific technology must start with a definition of terms, supporting fundamentals, and an understanding of technology's place in American culture and its contribution to the American way of war. By focusing on a specific technology's development process, stealth in this case, the many ways in which technology influences war may be better understood. With the importance of technology to the American way of war established, the requirement to provide a flow of superior technologies becomes obvious.

Definitions

Stealth.

Stealth is the popular name attributed to a combination of techniques and technologies that allow the control of observability, or signature control. It functionally covers six disciplines: electromagnetic, including radar, infrared (IR), visual, acoustic, smoke, and contrails.[1] It is not solely applied to counter radar detection as is popularly believed and cannot make a vehicle invisible to radar as some would imply. Stealth universally challenges the enemy across the spectrum of critical war related technologies by dramatically increasing the enemy's difficulty in detecting, tracking, guiding, or controlling airborne weapons and in predicting their future position in space.

Degrading some or all of these capabilities minimizes the enemy's opportunities to successfully employ various gun, aircraft, missile, and potentially laser beam guidance weapons. Degrading these capabilities also increases the probability that a stealthy vehicle can accomplish its mission and increase its survivability, while degrading the accuracy and completeness of the

adversary's information. The result is tactical, and perhaps operational surprise. Other associated terms include signature control, Radar Cross Section (RCS), signature interaction, Low Observable (LO), and Very Low Observable (VLO). Of these, signature may be the most basic. A weapons systems signature is the set of characteristics that describe a weapons system's susceptibility to detection.

Signature Interaction.

RCS is the apparent area of a target as seen by radar. It is based on a reflective sphere (think of a spherical mirror in the visual sense) that would return the same amount of energy. The apparent area, defined as the projected area, of that sphere is the RCS equivalent.[2] As an example, a small efficient reflector can reflect as much energy as a very large sphere.[3] The actual RCS further depends on the radar's frequency, polarization, angle of incidence of the transmitted wave form, and the shape and composition of the target.[4] The IR signature is the measure of amount of energy emitted and reflected by a target within a specified wavelength region of the IR spectrum.[5] As the previous examples demonstrate, electromagnetic, IR, acoustic, avionics, and visible signatures are definable, measurable and contribute to the overall weapons system signature. The individual signatures must be understood singularly and in combination. They must be designed to be effective with respect to the anticipated mission and real world environment. If any one of the signatures stand out with respect to their respective background environments, the weapons system could be compromised. The example of a stealthy aircraft that is not detectable by radar, flying at night with its lights on, illustrates this relationship. Although its radar signature has been effectively reduced, its visual signature stands out,

providing an easy means of visual detection. This in turn defeats the purpose of the radar signature reduction.

An aircraft's visual signature makes it vulnerable to Anti Aircraft Artillery (AAA) within a relatively small envelope. Radar, on the other hand, exerts its influence across the entire spectrum of air combat, making it the greatest threat and object of the most attention.[6] Unlike infrared, radar is very precise and can track range, velocity, and acceleration.[7] For aerodynamic systems, including aircraft, cruise missiles, and remotely piloted vehicles, the principal and most difficult design goal has been RCS reduction because large changes in RCS are required to make small changes in the ability of a radar to detect an object.[8] However, as RCS is reduced, the reduction of other observables, visual in the example above, becomes critical. As a minimum, the reduction of the IR emissions from hot exhaust gases, which limit detection by Infrared /Search and Track Systems (IRSTS), normally goes hand-in-hand with RCS reductions.

Low Observable (LO).

A LO system is defined as a system that utilizes a limited application of signature control. A radar LO system is typically characterized by a signature reduction over a limited range of frequencies and aspect angles. Treatments normally include the application of radar absorbing materials (RAM), minor modifications to the shape, and the addition of emission suppression devices.[9] If RAM is being integrated into the load bearing structure it is called Radar Absorbing Structure (RAS).[10] Like the RCS itself, the effectiveness of RAM varies with frequency, angle of the incident radar wave, and its own thickness and weight.[11] One can think of RAM as an "Electromagnetic Roach Motel -- radar waves checking in, but not checking out."[12]

The transition from the B-1A to B-1B is good example of the application of the LO process. A significant RCS reduction, from that of the B-1A, was achieved by modifying the existing conventional design with limited use of new materials and technologies.

Very Low Observable (VLO).

The term stealth is associated with a specific range of RCS and is defined as a comprehensive application of signature control over a large range of frequencies and aspect angles. It is equated with the term VLO and is usually based on radically new design concepts that make aggressive use of new materials and technologies. The F-117A is probably the first and most well known example of this comprehensive process. The B-2A and F-22 designs are improving integration of stealth techniques and reducing the operational limitations associated with earlier signature reduction efforts. Stealth, then, is not just the reduction of RCS, with which it is widely associated, nor is it the correct term for the entire spectrum of signature reduction. The term correctly refers only to the more effective and comprehensive VLO subset. The two attributes that differentiate stealth from the basic concept of LO are magnitude and breadth.

First, the term stealth connotes at least an order of magnitude of signature control beyond LO. Second, that signature control not only applies across a significant portion of the radar bandwidth, but also across the entire spectrum of militarily effective sensor operations. Stealth then applies signature control comprehensively across targeted spectrums with an order of magnitude in signature reduction. Now that we've established what stealth is, it is doubly important to understand what stealth is not. Although stealth embodies a comprehensive effort at signature control, it does not produce invisibility in any spectrum, including radar. What stealth does is limit the probability of intercept which further limits the probability of engagement,

increasing survivability and thereby the likelihood of mission accomplishment. It is generally impossible to enter an enemy's space without detection, but stealth reduces the opportunities for engagement and increases survivability and the probability of mission accomplishment.

The Effect of Stealth in Battle

Although not invisible, a stealth platform's ability to delay detection and degrade track information is a powerful contributor to masking intent and denying the enemy opportunities to efficiently marshal his forces. In a fundamental sense, stealth is the ability to surprise the enemy operationally and tactically. Sun Tzu asserts that all warfare is based on deception which assures that decisive blows may be struck where the enemy does not expect them and is consequently not prepared.[13] Perhaps his most important dictum concerning war is to attack the enemy's strategy.[14] If the enemy can be distracted or surprised in some fashion, decisive blows may be applied to his strategy making his success more likely. An aircraft, that through the use of deception (delayed detection or severely limited engagement opportunities in the case of stealth), can deliver a blow against a strategic target is indeed a significant tool. Carl von Clausewitz, although diminishing the usefulness of surprise by limiting its effectiveness to the tactical environment, does identify secrecy (a stealth attribute) and speed (an aircraft attribute) as the two factors that produce surprise.[15]

In this day of satellite scrutiny, strategic surprise in its traditional form may have become all but impossible, unless it is the product of technical innovation.[16] Surprise, as a factor in strategy, is an aspect of that other cardinal principle of war, concentration. Since superiority everywhere is normally unattainable, the main objective of most military movements is - or should be - to achieve relative superiority at some chosen point. If the enemy knows where you plan to

concentrate, you are not likely to attain superiority there. So the principle of surprise, the other side of the coin called concentration, is one of the vital elements of strategy.[17] As will be discussed later, the combination of stealth and precision in the F-117 produce surprise and concentration (mass) in a single capability.[18]

During war, a commander must be prepared for the fact that information will invariably be incomplete and inaccurate.[19] One of the most significant contributors to the poor quality of information is the friction in war[20], a phenomenon Clausewitz defines as the force that makes the seemingly easy task difficult.[21] Clausewitz would immediately see the advantage of presenting the adversary with inaccurate and incomplete information, although he may have some misgivings on allocating significant national assets to the development of the technologies and manufacturing processes required. Sun Tzu would embrace the ability to attain surprise even as Clausewitz would caution not to spend excessive effort in its achievement. From this basis of definition and application we will review the American way of war.

The American Romance with Technology

Technology is imbedded in America's culture and plays a critical role in how we view problems and our approach to solving them. So it follows that technology has become a key component of America's approach to conflict. According to Michael E. Howard, "War cannot be abstracted from the environment in which it is fought; it is inextricably tied to the peoples who fight it, and consequently to their cultures, religions, ideologies, economies, and technologies--to the totalities of their societies."[22] The uniqueness of America's experience, including technology's crucial contribution to the American way of war and its significant input in determining U.S. national security policy options, has a critical impact on our thinking about war.

The benefits of technological superiority to a war effort and the requirement to gain and maintain a technological advantage in peacetime has been a consistent theme in America's recent conflicts. Army Chief of Staff Eisenhower counseled other Army leaders that the technological expertise contributed by scientists and industrialists enabled the U.S. to outwit and overwhelm the enemy. He further stated that these civilian resources must be integrated into the national security planning process in order to fully exploit their capabilities.[23] Fleet Admiral King put it forcefully in his final report to the Secretary of the Navy: "Only by continuing vigorous research and development can this country hope to be protected from any potential enemies and maintain the position which it now enjoys in possessing the grates effective naval fighting force in history"[24]

The United States Strategic Bombing Surveys, a comprehensive effort to evaluate the effectiveness of strategic bombing after WWII, recommended the development of newer type offensive weapons and tactics.[25] It further stated that future national security will depend to a large degree on the technical superiority of our weapons and the proficiency of those who operate and maintain them.[26] Vannevar Bush, head of the Office of Scientific Research and Development capsulated the thinking of the senior U.S. leadership after WWII in his Presidential report, *Science: The Endless Frontier*,

> We cannot again rely on our allies to hold off the enemy while we struggle to catch up. There must be more----and more adequate military research in peacetime. It is essential that the civilian scientists continue in peacetime some portion of those contributions to national security which they have make so effectively during the war.[27]

The technology lessons learned from the Gulf War forty-five years later were nearly identical except that the U.S. did not have to catch up. The U.S. possessed the technological edge and the means to employ it. This resulted in describing the technological contribution to the

war in terms that are somewhat unusual. Technology was identified as playing a critical role in achieving an efficient and safe victory.[28] The Gulf War demonstrated that the U.S.'s highly sophisticated development process, where technological concepts are translated into a functioning capability, works and is worth the effort and expense.[29]

American Way of War

Doctrine's Role.

The American way of war translates technical dominance into doctrine. A basic consideration is that military doctrine must exploit superior weapons to the utmost and synergistically use areas of superiority.[30] The quality and quantity of weapons procured is an example of an issue that is embedded in the ongoing doctrine debate. As early as the days immediately following WWI the Air Service of the American Expeditionary Force (AEF) concluded that better aircraft proved more desirable than more aircraft.[31] This debate continued during the early 1970's with the development of the more expensive F-15 vice less capable and less expensive fighters. I.B. Holley linked the importance of both better aircraft and doctrine with these words, "WWI emphasized the necessity for a conscious recognition of the need for both superior weapons and doctrines to ensure maximum exploitation of their full potential."[32] The F-117 is a recent example of the U.S. technological approach to war.

Lessons from WWII built on WWI's, but broadened the focus to include the human element both in combat and in supporting roles. Technology may have lessened, but did not replace the human elements in warfare---courage, loyalty, skill and organizational ability were crucial to the outcome of the conflict, both on the battlefield, in the laboratory, and in the factory.[33] Quality and quantity; human abilities and technology; and combat and support have

been competing for relative merit in the American way of war. The ability of doctrine to guide this competition has been intermittent.

Air Power.

America is a maritime nation, but even more, America is an aerospace nation.[34] America not only invented the airplane, but currently leads the world in all major associated metrics, including civil aircraft production, key technology advances, pilots, military air power, and national air infrastructure. America's position as a leader in aerospace naturally influences its use of military air power. Therefore air power is a quintessentially American form of war. It emphasizes the advantages of mobility and high technology to overwhelm the enemy without spilling too much American blood.[35] All components can attack an adversary's centers of gravity, but only air power can frequently circumvent enemy forces and attack strategic targets directly. The result is fewer casualties on both sides.[36]

Since the development of the combat aircraft, air power has set the American way of war apart from other nations' approaches. Only the U.S. has engaged in a single-minded and successful quest for air superiority in every conflict since WWI. This doctrine continues to be emphasized over the quantum increase in the effectiveness of air power since the Vietnam war. Air warfare remains high tech, relatively safe and (at least in theory) quick. To America's enemies, past, current, and future, it is a distinctively American form of military intimidation. Air warfare plays to the machine-mindness of American civilization.[37] General Welch, former AF Chief of Staff, believes that air power is well suited to the preferred "American way of war": short, decisive, as bloodless as possible for U.S. ground forces.[38] It also does not commit the U.S. to a long term military liability. Air power can move in and out quickly.[39]

Other diverse external forces also come into play. For the U.S. the conduct of military operations in any security stetting is constrained by numerous public considerations. A relatively low tolerance for protracted military action resulting in high casualty levels has characterized the last half century. The twentieth century American strategic culture demands that U.S. military casualties be limited by high technology weaponry and the rapid and decisive defeat of an adversary.[40] The U.S. now plans to win any war it enters. This, by necessity includes the capability to undertake decisive counter offensive operations while minimizing casualties.[41]

Stealth Fits.

Stealth fits the American concept of warfare "like a glove." It exploits the nation's technological strength by inundating enemies with mass and maximizing firepower while minimizing casualties.[42] The identification of the requirement for newer types of weapons and technical superiority occurred at the end of WWII.[43] Technology enhanced and multiplied the effectiveness of the USAF's long term doctrine, which advocated the packaging of air assaults to surmount the IADS challenge.[44] The full integration of stealth characteristics and PGMs, including cruise missiles, by the coalition forces during Desert Storm reached the current pinnacle of package employment. The inescapable conclusion is that an air power, supported by stealthy technological innovations and applications, was successfully employed offensively against an enemy's vital centers with a relatively small attrition rate. The ultimate contribution, of the technologies identified by the term stealth, is to enable the continuation of offensive air power's ability to hold key target sets at risk.[45]

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[1] *Aerospace Low Observables Capabilities--Foreign*, (U), (A Defense S&T Intelligence Study, DST-26605-774-92, 28 Feb. 1992), p 1.

[2] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 89.

[3] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 90. RCS simply does not operate in a linear manner. A ten cm by ten cm square plate (0.015 sq. m), positioned perpendicular to the radar beam, has an RCS of one sq. m, which is one hundred times greater that its area. Composite shapes are not additive and can have much larger RCSs if they include reflective panels mounted at 90 degrees, like the twin vertical tails of the F-15. The F-15 has an RCS of less than ten sq. m nose on, but more than 400 sq. m when looking at a fully exposed wing planform. Most of the power transmitted by radar goes to empty space or is reflected from the target, but in a direction away from the source. The radar receiver is sensitive enough to pick up the tiny component of the signal that is actually reflected back in the direction of the source radar. This sensitivity translates into the fact that a target's RCS is not directly proportional(fourth root) to the radar's detection range. This relationship means that it takes a ten-fold reduction in RCS to have an effect and a hundred-fold RCS reduction to seriously reduce detection range. A thousand-fold reduction will seriously limit modern air defense capabilities, virtually rendering them ineffective.[3] A typical conventional fighter has a RCS of five SQ. M, as large as a radar reflective sphere with a cross section of that size, which would be just over eight feet in diameter (.01M2 = 4.5 inch sphere and .001 M2 = 1.4 inch sphere).[3] It is for this reason that from the inception of radar, it has tended to outpace technical capabilities to disrupt it, especially in the area of signature reduction.[3]

[4] *Aerospace Low Observables Capabilities--Foreign*, (U), (A Defense S&T Intelligence Study, DST-26605-774-92, 28 Feb. 1992), p 1. RCS is usually expressed in Meters^2 or decibels (dB above (+) or below (-) 1M^2 [RCS (DBMS) = $10\log_{10}$RCS(m^2)]. In other words, a 1m^2 RCS equals 0 DBMS and 0.001 m^2 equals -30 DBMS. For a given radar, the detection range depends upon the RCS of the target. For example, a radar that can detect a one square meter target (the size of a T-38) at 100km will be unable to detect a 0.001m^2 target (the size of a golf ball) until it comes to within 18km of the radar.

[5] *Aerospace Low Observables Capabilities--Foreign*, (U), (A Defense S&T Intelligence Study, DST-26605-774-92, 28 Feb. 1992), p 1. The total amount of energy depends on target speed, its emissivity and reflectivity, and internal heat sources such as operating engines and their exhaust plumes. The external environment, solar and earth shine, as well as absorption of the atmosphere, play an important roll in ultimate use. IR signature is usually measured in watts per steradian.

[6] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 87.

[7] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 87.

[8] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 88. Technically, a radar's detection range is proportional to the fourth root of the target's RCS.

[9] *Aerospace Low Observables Capabilities--Foreign*, (U), (A Defense S&T Intelligence Study, DST-26605-774-92, 28 Feb. 1992), p 1.

[10] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 107.

[11] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 110.

[12] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 111.

[13] Sun Tzu, "Sun Tzu The Art of War," trans by Samuel B. Griffith, (USA, Oxford University Press, 1963), p 106 & 43.

[14] Sun Tzu, "Sun Tzu The Art of War," trans by Samuel B. Griffith, (USA, Oxford University Press, 1963), p 77.

[15] Carl von Clausewitz, *On War*, ed and trans Michael E. Howard and Peter Paret, (Princeton, NJ, Princeton University Press, 1984), p 198.

[16] Irving B. Holley, "Technology and Strategy: A Historical Review," *Technology, Strategy and National Security*, ed by Franklin D. Margiotta and Ralph Sanders, (National Defense University Press, Washington D.C., 1985), p 36.
[17] Irving B. Holley, "Technology and Strategy: A Historical Review," *Technology, Strategy and National Security*, ed by Franklin D. Margiotta and Ralph Sanders, (National Defense University Press, Washington D.C., 1985), p 18.
[18] John A. Warden III, Col, USAF, "Air Theory for the Twenty-first Century," *Challenge and Response Anticipating U.S. Military Security Concerns*, ed by Karl P. Magyar, (Air University Press, Maxwell AFB, Alabama 36112-6610, Aug 1994), p 329.
[19]Carl von Clausewitz, *On War*, ed and trans Michael E. Howard and Peter Paret, (Princeton, NJ, Princeton University Press, 1984), p 117.
[20] Carl von Clausewitz, *On War*, ed and trans Michael E. Howard and Peter Paret, (Princeton, NJ, Princeton University Press, 1984), p 117.
[21]Carl von Clausewitz, *On War*, ed and trans Michael E. Howard and Peter Paret, (Princeton, NJ, Princeton University Press, 1984), p 121.
[22] *Basic Aerospace Doctrine of the United States Air Force*, (Air Force Manual 1-1, Volume II, March 1994), p 5.
[11] This approach is the basis of Michael E. Howard, *War in European History* (London: Oxford University Press, 1976), and of Richard A. Preston and Sydney F. Wise, *Men in Arms: A History of Warfare and its Interrelationships with Western Society*, 4th ed. (New York: Holt, Rinehart and Winston, 1979), especially 8-11; see also John G. Stoessinger, *The Might of Nations: World Politics in Our Time*, 8th ed. (New York: Random House, 1986), 13-27.
[23]David K. Allison, "U.S. Navy Research and Development since World War II," *Military Enterprise and Technological Change*, ed by Merritt Roe Smith, (Cambridge, MA, The MIT Press, 1987), p 290.
[24]David K. Allison, "U.S. Navy Research and Development since World War II," *Military Enterprise and Technological Change*, ed by Merritt Roe Smith, (Cambridge, MA, The MIT Press, 1987), p 291.
[25]*The United States Strategic Bombing Surveys*, (Maxwell AFB, AL, Air University Press, October 1987), p 114.
[26]*The United States Strategic Bombing Surveys*, (Maxwell AFB, AL, Air University Press, October 1987), p 116.
26David K. Allison, "U.S. Navy Research and Development since World War II," *Military Enterprise and Technological Change*, ed by Merritt Roe Smith, (Cambridge, MA, The MIT Press, 1987), p 291.
[27] *United States Bombing Survey*,
[28]Brian E. Wages, *The Gulf War, An Airman's Perspective*, (Arlington, VA, SDS International, 1993), p 34.
[29]Brian E. Wages, *The Gulf War, An Airman's Perspective*, (Arlington, VA, SDS International, 1993), p 36.
[30] I.B. Holley, Jr., *Ideas and Weapons*, (Yale University Press, 1953), p 150.
[31] I.B. Holley, Jr., *Ideas and Weapons*, (Yale University Press, 1953), p 152.
[32] I.B. Holley, Jr., *Ideas and Weapons*, (Yale University Press, 1953), p 175.
[33] Ralph Sanders, "Three-Dimensional Warfare: World War II," *Technology In Western Civilization Volume II*, ed by Melvin Kranzberg and Carroll W. Pursell, Jr., (Oxford University Press, New York, New York, 1967), p 578.
[34] Donald B. Rice, "Global Reach--Global Power The Evolving Air Force Contribution to National Security," *AWC Department of Military Studies Readings: Book 2 Military Studies Course--MS 610*, ed by Col Bryant P. Shaw and Dr. William P. Snyder, (Maxwell AFB, AL, Air University, June 1994),[Reprinted from *Global Reach Global Power, the Evolving Air Force contribution to National Security*, pp 1-15. Published December 1992, by the Department of the Air Force], p 307.
[35]John A. Warden III, Col, USAF, "Employing Air Power in the Twenty-first Century," *The Future of Air Power in the Aftermath of the Gulf War*, ed by Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., , (Air University Press, Maxwell AFB, AL , July 1992), p 61.
[36] John A. Warden III, Col, USAF, "Employing Air Power in the Twenty-first Century," *The Future of Air Power in the Aftermath of the Gulf War*, ed by Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., , (Air University Press, Maxwell AFB, AL , July 1992), p 61.
[37] Eliot A. Cohen, "The Mystic of U.S. Air Power," *AWC Department of Military Studies Readings: Book 2 Military Studies Course--MS 610*, ed by Col Bryant P. Shaw and Dr. William P. Snyder, (Maxwell AFB, AL, Air

University, June 1994), [Reprinted from *Foreign Affairs*, January-February, Vol. 73, No. 1, pp. 109-124. Published in 1994 by the Council on Foreign Relations.], p 312.

[38] Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., "Air Power as an Element of US Power Projection: Introduction," *The Future of Air Power in the Aftermath of the Gulf War*, ed by Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., (Air University Press, Maxwell AFB, AL , July 1992), p 94.

[39] Larry D. Welch, Gen, USAF, "Air Power in Low- and Midintensity Conflict," *The Future of Air Power in the Aftermath of the Gulf War* , ed by Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., , (Air University Press, Maxwell AFB, AL , July 1992), p 140.

[40] Richard H. Shultz, Jr. and Robert L. Pfaltzgraff, Jr., The Future of Air Power in the Aftermath of the Gulf War, (Air University Press, Maxwell AFB, AL , July 1992), p 51.

[41] Paul K. Davis, New Challenges for Defense Planning, Planning Under Uncertainty Then and Now: Paradigms Lost and Paradigms Emerging, (RAND, MR-400-RC, 1994), p 32.

[42] *Basic Aerospace Doctrine of the United States Air Force*, (Air Force Manual 1-1, Volume II, March 1994), p 5. Note: Technology has always been the willing partner of air power. The mastery of the environment in which air power operates, by definition, requires technology more that any other medium. Douhet counted on technology to realize his vision.

[43] *The United States Strategic Bombing Survey*, p 114, 116.

[44] Basic Aerospace Doctrine of the United States Air Force, AF Manual 1-1, Vol 1,(March 1992), p 6. Note: The packages, generally consisting of the primary attack aircraft and a varying number and type of supporting specialized aircraft, were designed to enhance survivability while increasing effectiveness. An example of an early package was the tasking of long range fighters to escort heavy bombers to their targets in WWII. The mission was the same as during the Gulf War--penetrate the IADS with acceptable losses. Specialized radar spoofing aircraft were added to the packages before the end of the war. Package composition and tactics matured during the Vietnam war when confronted with the ever increasing destructive capability of the North Vietnamese IADS. Perhaps the best example of package integration and employment prior to Desert Storm was the execution of the Israeli SEAD campaign over the Bekaa Valley in 1982.

[45] William P. Snyder, Professor AWC faculty, Effective Writing Lecture, 13 Oct 94, 10:15. Note: Prof. Snyder advocated writing for an audience typified by a teenage daughter. A teenage daughter not being available for an example, a third grade son was substituted. The following analogy reflects Prof. Snyder's advocacy. The development and use of stealth technologies is analogous to the purchase and use of man's best friend. the potential dog owner must first formulate his or her objective for the animal, whether it be working, hunting, or family pet. Then the owner must proceed with breed selection based on the requirements, investigation of the bloodlines, and observation of the parents. Once the canine is selected, the owner must feed, train, and treat the animal right. If this pattern is followed, the hound will fulfill the owner's objectives. An even more direct analogy could be made if the audience was identified as the population surrounding the AWC (Montgomery, AL). This dog ***will*** hunt.

CHAPTER 3 -- Why Stealth?

Throughout the history of warfare, man has sought to develop newer, more effective weapons and tactics to gain an advantage over his adversary. When confronted with these new capabilities, the opposing military would develop counters to these new weapons and employment techniques. Thus the shield was developed to counter the sword, the tank developed to counter the machine gun and ECM, force packaging, and stealth were developed to counter radar. The evolution of the development of radar and stealth is just another example of the process of adversaries developing counters to new technologies.[1] In effect, each a motivator for the other's development.

Britain's pre WWII air defense problem centered around the inability to accurately detect incoming bombers in a timely manner and then marshal an effective response with the resources available. Because of the limited daytime detection capability and a lack of detection capability at night, these bombers were effectively "stealth" bombers. The following pages illustrate how radar developed a capability that neutralized the bombers' surprise and effectiveness . Which came first? The chicken or the egg? Let it suffice to say that neither radar or stealth is a new concept and both are potent forces struggling to overturn each tentative balance struck between the competing technologies. A review of the development approaches of these two technologies provide provides a useful means to understanding their relationship and the different acquisition systems that produced them. Radar was a direct result of a mission requirement dictated by doctrine. The relationship between the development of stealth technologies and doctrine is less clear.

History of Radar Development

Radar's Genesis.

Two Germans built the foundation for the development of radar. Henrich Hertz demonstrated that radio waves could be reflected off of metallic objects in 1897 and Christian Hulsmeyer patented such a device through the Royal German Patent Office in 1904.[2] In 1921 Dr. Albert Hall of General Electric invented the magnetron which reduced the transmitted wavelength, resulting in increased accuracy while maintaining adequate power output. This development enabled radar's subsequent myriad applications.[3] Radar development, particularly after 1930, was progressing simultaneously in Britain, Germany, and the United States. Each nation had correctly anticipated the powerful potential of the technology and were therefor proceeding in total secrecy. Although the British had been calling the technique Radio Detection Finding (RDF), two American naval officers, F.R. Furth and S.M. Tucker, coined the name that eventually stuck, Radio Detection And Ranging (radar).[4] This name was adopted officially in 1943.[5] The race for radar was on, but the British lead the way in application, combining radar's capabilities with existing infrastructure through a doctrine that solved their air defense dilemma.

The Problem.

After WWI, Air Power theorists, such as Italy's General Guilio Douhet, argued that there was no practical defense against a massed bomber raid.[6] A British politician and former prime minister, Stanley Baldwin, campaigned for aerial disarmament. "The man in the street, should realize," he said in November 1932, "that there is no power on earth that can prevent him from being bombed...the bomber will always get through." This was basically the case in 1932.[7] During the 1934-1939 expansion of the Royal Air Force (RAF), the difficulty of defending the

British Isles form air attack received the bulk of the attention. The problem was seemingly intractable. The initiative was in the hands of the attacking bomber, which had the choice of time, target, route, and altitude. To make matters worse, the potential threat could reach any target in England in less than twenty minutes after crossing the coast. A fighter, if launched immediately, might require ten minutes just to climb to altitude in order to be in position to begin an intercept. It was clear that a large number of contiguous airborne patrols would be necessary if the RAF was to have any chance of intercepting the bombers before they reached their targets. The adoption of a strategy that would require 24 hour patrols would require an enormous force, a force that was clearly impossible to build and operate with the resources available to prewar Britain.[8] The Air Ministry began a motivated search for a solution to the problem that ranged from theories taunting the use of disabling energy rays to the previously developed acoustic sensor network. The energy ray concept remained in the future and the capability of the acoustic network had already become positively overwhelmed by the increases in aircraft speed.[9] Near the end of 1934, the Air Ministry Director of Scientific Research, H.E. Wimperis, convened an ad hoc committee composed of himself, the chairman of the Aeronautical Research Committee and former Royal Flying Corps (RFC) pilot, H.T. Tizard, and two professors, P.M.S. Blackett and A.V. Hill. A scientist from the Directorate, A.P. Rowe joined them.[10] The RAF had a serious problem, upon which the very survival of their nation might rest, and that none of the suggested approaches appeared viable. A talented and result oriented interdisciplinary group was formed quickly to survey the challenge.

The committee met on January 28, 1935 and concluded that detection, not destruction of incoming aircraft by radio waves had some promise. They then decided to seek the advice of the

superintendent of the Radio Department of the National Physical laboratory, R.S. Watson Watt. By the twelfth of February Watt had explained to the committee how he thought transmitted radio pulses would be reflected off the metal component of aircraft and that this reflection could then be recorded. A practical demonstration was executed successfully on February 26th followed by the commitment of considerable resources and rapid development. By 1935 initial production had been authorized and by the outbreak of the war in 1939, 20 stations were operating in Britain and three overseas.[11] The process was fraught with difficulties and delays, but the overall speed with which radar was developed and employed represented an extremely short time from untried theory to large scale practical application, especially given the all encompassing governmental participation.[12]

Multiple Applications.

Radar showed a capability to cope with a wide variety of military needs and was pushed quickly into many applications. It enabled the British to provide detection and quantification of approaching German air attacks allowing the efficient use of their fighter force during the Battle of Britain. The RAF envisioned the use of long range radar to guide fighters to the attacking bombers and short range systems to aim AAA and searchlights. The RAF even believed that equipping individual aircraft with the new technology would be possible in the near future. When the Germans switched to night attacks, the British and Americans combined to develop an airborne microwave search radar for night fighters. Radar was then used to give the bomber force more capability at night and in weather by using an air to ground mapping mode. A similar airborne radar was used to detect submarines operating on the surface during the Battle of the

Atlantic. The Royal Navy was also interested in detecting shipping from shore based installations and from other ships.

Radar improved the effectiveness of both direct and indirect fire weapons through the introduction of the proximity fuse, a small radar transmitter and receiver that senses a set distance to the target and detonates the shell at the most effective position. Critical distance and speed information provided by radar vastly improved a myriad of fire-control systems. The broad based effectiveness of radar naturally spurred the development of countermeasures by both sides.[13]

Exploitation.

The radar concept enjoyed a rapid and comprehensive exploitation in the areas of technology improvement, applications and countermeasures. As early as 1939 the British had designed every predictable countermeasure and counter-countermeasure into their air defense system.[14] Perhaps the most important aspect of the British development was the quick incorporation of radar's detection capabilities into the air defense system. The existing communication and control system was modified to make use of the new detection information. Exercises were scheduled to develop procedures and train the operators. The concept of the operations room, or filter center, controlling the battle by launching ground alert fighters against known targets just in time to execute the intercept had the effect of multiplying the existing fighter force may times over.[15] The RAF Fighter Command alone succeeded in finding a way to channel pertinent information, based on radar plots, to the fighter forces by radio.[16] There were insufficient resources to use fighters to patrol continuously, but the air defense problem had been resolved in a very short time by a small group of highly motivated experts working together to

solve a difficult problem in a secret environment. The development of stealth technologies will exhibit an amazingly similar number of these characteristics.

Counters.

Radar counters followed closely on radar's heels. By 1941, nearly all of the fundamental forms of Electronic Warfare (EW) had been identified. Passive instruments that informed a bomber crew that they had been detected, clouds of aluminum foil that inundated adversary radars by producing large numbers of radar returns, and a wide spectrum of jammers, from radio to radar, that saturated radar screens or masked verbal communication began to offset radar's gains. Countermeasures including metallic strips called "window" or "chaff" cluttered the radar scope. When combined with additional noise provided by electronic jammers, code named "Carpet," the early radars were degraded seriously.[17] Deception, in the from of obsolete bombers used to draw enemy fighters from the real effort, was also successfully used a number of times to reduce the effectiveness of radar's warning and command and control functions.[18] The measure - countermeasure - counter countermeasure process, with respect to radar, had been initiated.

The Integrated Air Defense System (IADS) Challenge

As a result of the increasing capability of air power, the Soviet-Warsaw Pact developed a model of air defense characterized by an elaborate integrated network that included warning sensors, AAA, fixed and mobile SAMs, and airborne interceptors using Ground-Controlled Intercept (GCI) procedures. These assets are then employed in multiple layers by a dedicated command and control (C2) system.[19] The air defense of North Vietnam during the Vietnam War firmly established the capability and threat of the IADS concept. The Middle East air wars following the Vietnam War contributed similar learning outcomes.[20] In the 1973 Yom Kipper

war, the Israelis lost 109 aircraft in eighteen days, mostly to radar guided SAMs and AAA. In the simplest terms it was a confrontation between U.S. designed aircraft (Israelis) and the Soviet IADS (Egyptian and Syrian)[21]

These air wars highlighted the requirement to neutralize the IADS in order to implement the selected strategy with acceptable losses. The severity of IADS challenge demanded that it be approached from a number of different avenues. Countermeasures developed quickly and eventually included a number of active and passive, as well as technical and tactical techniques. The most refined, and commonly used, response was to combine specialized support aircraft and the on-board warning and countermeasures systems of the individual strike aircraft into an integrated mutually supporting package.[22] Combining technology, doctrine, and tactics in this package process had the effect of confusing specific cause-effect relationships. In other words the effect of each counter could not be specifically quantified or evaluated. Only the overall result was apparent.

The Mission to Penetrate the Soviet IADS

The following examples illustrate the means by which the IADS challenge was addressed, initially through over flight at high altitude and followed by increasing speed, altitude and finally by adding ECM and signature control capabilities. The point-counter point paradigm is clearly in evidence when the development of the U-2, A-12, YF-12, SR-71, and D-21 are examined.

The U-2.

The U-2 is an excellent example of a platform designed to meet the IADS challenge, primarily through over flight at high altitude. By flying at an altitude beyond the reach of SAMs,

it could furnish a plethora of targeting information in the form of high quality pictures, not available from any other source. It was used primarily to gather information about a large number of the old Soviet Union's militarily significant targets, including railroads, power grids, industrial facilities, nuclear plants, military capabilities and mission.[23] The first U-2 flight was on July 23rd, 1955.[24] On its first missions over Russia, the U-2 was tracked easily by the IADS using U.S. furnished lend lease early warning radars that had been improved by the Russians. The ability to track the U-2 caused much concern and proved to be another key motivator in the quest for a solution to the IADS problem.[25]

The advent of an improved SAM, the SA-2, upped the ante in 1956, increasing the danger to the U-2 and threatening to stop the flow of valuable information it was providing. Various counter radar techniques were attempted: several radar absorbing paints, piano wire, of various dipole lengths strung along the fuselage (this resulted in too much drag), and the Salisbury screen, a metallic grid applied to the undercarriage (its effectiveness was limited to specific frequencies and altitudes).[26] An ECM capability, designed to degrade adversary radar capability, was installed eventually in the tail.[27] The U-2 spent nearly four years over flying Soviet Union airspace, 1956-1960, till Francis Gary Powers was shot down.[28] They continued to fly from Kadena, logging twenty-two missions in 1967 and becoming the target for at least seven SAMs.[29] Six of those SAMs were fired on one mission.[30] At least six more missions were flown in 1968, but without additional speed or stealth the U-2's capability to penetrate targets heavily defended by SAMs was coming to an end.[31]

The High Fast Flyers: A-12, YF-12, SR-71 and D-21.

None of the embryonic stealth technologies used on the U-2 proved effective and ultimately resulted in the design of a new aircraft to counter the threat. Richard M. Bissell, Central Intelligence Agency (CIA), contracted for a study relating the affects of speed, altitude, and RCS on the probability of being shot down in 1957. The study noted that supersonic speed significantly reduced the aircraft's SAM vulnerability envelopes and that the synergistic effect of using speed and low RCS to reduce SAM envelopes improved survivability to the point that the risk of an aircraft being shot down was minimized dramatically. This aircraft would use a combination of speed, altitude, and designed in RCS reduction to decrease its vulnerability. The concept still applies today and is the driver behind the characteristics of the F-22 today.[32]

The A-12 became the successor to the U-2 and predecessor of the SR-71.[33] Lockheed was given the A-12 go ahead in 1959 after a year long competition with Convair.[34] The first A-12 flight occurred on April 26th 1962 and the program was terminated 1968.[35] The program completed fifteen aircraft under the code name *Oxcart*.[36] To reduce RCS, the A-12 design group pioneered the use of laminated plastic in the construction of the vertical tails. With an RCS of 0.015 SQ. M, one third of a that of a contemporary conventional fighter, and Mach 3.5 speed above 90,000 feet, SAM envelopes were reduced effectively to insignificance.[37] The A-12 was one of the first aircraft to undergo RCS model testing,[38] requiring the construction and use of radar test ranges beginning in 1959.[39] The methods learned in the construction and use of these ranges would prove critical to the development of future stealth technologies.

The A-12 program should be used as a model for the development, production and operation of a highly complex aircraft and may prove useful to contrast it with any current

program. It was conceived, contracted, delivered and flown for six years, all in the space of ten years. Timely superiority, applied through an appropriate doctrine, and in the quantity required is a concept that builds on the technology lessons of WWI that were cited earlier .

The YF-12 fighter version, a heavier two seat version of the A-12, was subsequently ordered by the USAF, but sacrificed RCS reduction to improve the aircraft's military usefulness.[40] Although an example of a trade-off decision required on any project, it highlights the lack of understanding of the value of RCS at the time or, alternatively, acknowledges the lack of technical capability with respect to the magnitude of reduction possible. Although it was never deployed, the YF-12 came out of the black world in 1964 when President Johnson finally announced its existence as a long range interceptor.[41]

After discontinuing the YF-12, the USAF ordered 31 unarmed versions, eventually designated the SR-71 Blackbird. The SR-71s became operational in 1967[42], with the last aircraft delivered in 1971.[43] SR-71 goals, initially the same as the A-12's, included the capability to fly over Mach 3 at 90,000 feet without being detected. Sometimes claimed as the first stealth airplane, the SR-71 had a RCS significantly less that the of B-1B, which was fielded 25 years later.[44]

The SR-71 RCS, equivalent to that of a Piper Cub, was the result of its peculiar cobra shaping and the application of radar absorbent materials. The distinctive bullet shape of the SR-71 benefited from a 90% RCS reduction as a result of the addition of a chine along the length of the fuselage.[45] To further reduce the RCS, the SR-71 incorporated the application of radar absorbing ferrites and plastics to all of the aircraft's leading edges. The twin tails were also kept as small as possible and constructed from radar absorbing composites.[46] Because the total RCS of a platform

is generally composed of shaping (65%) and coatings (35%), the magnitude of reduction achieved was a significant step forward.[47] The low RCS was combined with an ECM capability installed in the tail to enhance survivability. Once the radar vulnerability was reduced, it became necessary to reduce the IR signature as well. A fuel additive was used to ionize exhaust gases in order to degrade IR detectors.[48] Lockheed eventually produced 15 A-12s, three YF-12As, and 31 SR-71s.

The success of the Blackbird resulted primarily from its speed and altitude capabilities, but also proved the value of RCS reduction. As successful as it was, the risks associated with losing an aircraft and crew over hostile territory resulted in the development of an unmanned drone with similar characteristics. The D-21 drone could fly higher and faster than the modified A-12 it was initially launched from, but suffered from reliability problems that could not be solved, even by changing the launch vehicle to a B-52.[49] Speed, high altitude, and initial signature control efforts were moderately successful, but the development of a truly comprehensive stealth capability would have to wait for technical advances in other fields.

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[1] Because radar is a very powerful tool scientists have sought the means to degrade its effectiveness and stealth has become one of the more recent means developed. Incomplete and inaccurate radar information will characteristically result in the inappropriate or sub-optimum use of the available forces. This, of course, would result in the following advantage: an enemy could maximize the effect of the forces he has brought to bear while enhancing their survival. The development of radar signature control, through RCS reduction, is another step the continuing radar measure and countermeasure contest that has been ongoing since the development of radar prior to WWII. Radar is a very powerful tool that has naturally become the focus of ways to degrade its effectiveness. In fact radar, or rather the ability to counter the information that radar provides, is the key to the entire stealth concept. These radar counters include both active (chaff, electronic warfare, and destruction by missiles or bombs) and/or passive (tactical formations, electronic warning systems, and signature control) techniques.

[2] Alfred Price, *Instruments of Darkness*, (Charles Scribner's & Sons: New York, 1977), p 38.

[3] Ralph Sanders, "Three-Dimensional Warfare: World War II," *Technology In Western Civilization Volume II*, ed by Melvin Kranzberg and Carroll W. Pursell, Jr., (Oxford University Press: New York, New York, 1967), p 573.

[4] Robert Morris Page, *The Origin of Radar*, (Anchor Books: Garden City, 1962), p 15.

[5] Denis Richards and Hilary St. George Saunders, *The Royal Air Force*, 1939-1945, p 25.

[6] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 8.

[7] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1989), p 10.
[8] Denis Richards and Hilary St. George Saunders, *The Royal Air Force* , 1939-1945, p 22.
[9] Denis Richards and Hilary St. George Saunders, *The Royal Air Force* , 1939-1945, p 22.
[10] Denis Richards and Hilary St. George Saunders, *The Royal Air Force* , 1939-1945, p 23.
[11] Denis Richards and Hilary St. George Saunders, *The Royal Air Force* , 1939-1945, p 23-25.
[12] Denis Richards and Hilary St. George Saunders, *The Royal Air Force* , 1939-1945, p 23-26.
[13] Ralph Sanders, "Three-Dimensional Warfare: World War II," *Technology In Western Civilization Volume II*, ed by Melvin Kranzberg and Carroll W. Pursell, Jr., (Oxford University Press: New York, New York, 1967), p 573-574.
[14] Jack Nissen and A.W. Cockerill, *Winning the Radar War*, (St. Martins Press: New York, 1987), p 27-28.
[15] Denis Richards and Hilary St. George Saunders, *The Royal Air Force*, 1939-1945, p 25.
[16] Alfred Price, *Instruments of Darkness*, (Charles Scribner's & Sons: New York, 1977), p 61.
[17] Ralph Sanders, "Three-Dimensional Warfare: World War II," *Technology In Western Civilization Volume II*, ed by Melvin Kranzberg and Carroll W. Pursell, Jr., (Oxford University Press: New York, New York, 1967), p 574.
[18] Bill Sweetman, *Stealth Bomber Invisible Warplane, Black Budget*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1989), p 14.
[19]Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (Smithsonian Institution Press: Washington D.C., 1992), p 25.
[20]Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (Smithsonian Institution Press: Washington D.C., 1992), p 62.
[21] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 17.
[22] Note: The expansion and diversification of electronic warfare research resulted in the fielding of the EF-111A Raven, a weapons system with the capability of both stand-off and penetration jamming, and the F-4G with its associated AGM-88 High-Speed Anti-Radiation Missile (HARM). The F-4G could target and launch the HARM, which then guided on the emissions of the target radar, to prevent the SAMs from engaging friendly aircraft.
[23] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 125.
[24] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 134.
[25] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 146.
[26] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 152.
[27] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 157.
[28] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 41.
[29] "Blackshield," Air Force Magazine, January 1995 (Vol. 78, No. 1), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p67.
[30] "Blackshield," Air Force Magazine, January 1995 (Vol. 78, No. 1), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 69.
[31] "Blackshield," Air Force Magazine, January 1995 (Vol. 78, No. 1), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 70.
[32] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 42.
[33] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 41.
[34] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 42.

[35] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 45.
[36] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 13.
[37] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 14.
[38] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 14.
[39] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 43.
[40] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 14.
[41] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 46.
[42] "The Oxcart Story," Air Force Magazine, November 1994 (Vol. 77, No. 11), (Air Force Association, 1501 Lee Highway, Arlington, VA 22209-1198), p 47.
[43] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 14.
[44] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 215.
[45] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 198-199.
[46] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 197.
[47] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 24.
[48] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 240.
[49] Bill Sweetman and James Goodall, *Lockheed F-117A Creation and Development of the Stealth Fighter*, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1990), p 15.

CHAPTER 4 -- F-117 Development

Condensed Early History of Stealth

Militaries have been urging the scientific community to counter radar ever since the British turned the first air defense versions on prior to the Battle of Britain. Although stealth is treated as a new phenomenon, interest in signature reduction, can be arguably traced back to at least WWI or before. Efforts at aircraft signature reduction began shortly after the aircraft evolved as a weapon of war. In 1912, Hauptman (Captain) Petrocz von Pertroczy tested a Etrich Taube monoplane covered with Emallit, a French produced transparent celluloid material in hopes that by reducing the visual signature of the aircraft he could improve the survivability of reconnaissance flights over enemy lines. A number of aircraft were tested over a four year period as Emaillit evolved into a German manufactured substance called Cellon. The Germans experimented with the clear cellophane skins on a Gotha bomber and a Fokker E.1 fighter during WWI.[1] Unfortunately Cellon could not withstand the challenge presented by moisture and no direct evidence was developed that supported the postulated relationship between reduced visibility and survivability.[2] This effort to control visual signatures was only the first of many.

Direct evidence or not, fighter pilots of all nations had been convinced of the importance of the capability to detect other aircraft first since the beginning of aerial conflict. "Lose Sight -- Lose Fight" is the enduring slogan of the fighter pilot. Years of experience supported the link between reduced visibility and increased survivability.[3] A number of corollaries soon developed. "If out numbered, duck into a cloud," is a good early example of an early tactical application of this thought process.

Project Yehudi was conceived in the early 1940s by the U.S. Navy as a means to reduce a German U-Boat captain's ability to visually detect patrol planes (a black dot against the sky) before the patrol planes could acquire the U-Boat (black object against a dark gray sea) and thus allow the U-Boat to dive and escape before the patrol plane could attack. Contrast in luminance was the source of this theory. The sky emitted more light energy than the aircraft so lights were fitted to key areas of the patrol bombers so that their intensity could be varied to match sky conditions. Although promising, the advent of air-to-surface radar killed the program.[4]

Efforts to reduce the visual detection range of the human eye continued into the 1970s. The United States Air Force (USAF) painted the bottoms of F-4s white or black during the Vietnam conflict (white to reduce visual detection ranges during the day and black to reduce them at night). Keith Ferris, the famous aviation artist, developed a number of geometric aircraft paint schemes designed to limit the human eye/brain's capability to determine the target aircraft's aspect or direction of flight. Again, the results were mixed and the paint schemes were not widely adopted. Viable techniques to reduce visual detection ranges would be extremely welcome today, as they would increase the flexibility of the F-117 fleet by expanding daytime operations.

Watson-Watt noted as early as 1935 that it would be logical for future heavy bombers to be designed so as to reduce their radar reflectivity.[5] Radar engineers developed a measurement for RCS, comparing the strength of the return from the target with that of a simple reflective sphere with a one-square meter cross section.[6] Radar engineers observed that radars would detect targets at greater or lesser ranges depending on the type of aircraft and the angle at which the radar beam struck it.[7] Two German brothers, Walther and Reimar Hortens, were the first aircraft designers to attempt to reduce radar reflectivity. They focused on the inherently low

radar reflectivity of the flying wing, designing a twin jet flying wing bomber and reconnaissance aircraft in 1943. Due to the shortage of materials in wartime Germany, they planned to build the plane with a central steel-tube frame with a non-absorbent plywood skin. The skin would be constructed of a core of glue, sawdust and charcoal sandwiched between two thin layers of plywood. The charcoal was probably the first knowingly designed in RAM. The external shape of the 1944 Horten HoIX, its internal RAM, and concealed placement of its highly reflective steel engines in the aircraft structure comes close to describing the current B-2.[8] The Horten HoIX was eventually tested in 1944, but came too late to help the German war machine and was summarily discounted, taking its charcoal RAM secret to the scrap pile with the rest of the machine. Construction of the Horten HoXVIII, a six jet long range bomber (flying wing) that had the capability to bomb New York from Germany, actually was started in April 1945.[9]

Altitude, Speed, and Stealth.

Stealth joined speed and altitude in a quest to reduce aircraft vulnerability. The B-29 was the first of many efforts to use increased altitude and speed to improve survivability.[10] The British Mosquito, built primarily of wood, which inadvertently reduced its radar signature in comparison to the heavy bombers of the day, also used the characteristics of high altitude and high speed to improve its survivability. It shares the attributes of reduced RCS, high altitude and high speed operations with the SR-71, although preceding it by 25 years.[11] Designed in 1957, the XB-70 also was intended to avoid jet interceptors and SAMs by high altitude (above 70,000 ft) and supersonic speed (Mach 3.0), but failed to incorporate stealth as a design characteristic.[12] Speed and altitude was not enough anymore. The B-70 was canceled finally in 1961 after the production of two prototypes.[13] Although it effectively forced the USSR to consume critical resources by

producing the Mig-25 Foxbat to counter the B-70, it continued to clog the U.S. acquisition system until it was permanently terminated in 1964.[14] However, the concept of stealth, and its associated degradation of detection, is not limited solely to aircraft.

The Submarine.

WWI provided a fertile ground of development for a reduced signature weapons system that was initially employed in 1864. In that year the Confederate States Ship (CSS) Hunley, an eight man submarine, sank the Untied States Ship (USS) Housatonic on February 17th.[15] The ability of the submarine to maneuver into a position to attack an adversary without being detected embodies the attributes of signature reduction. Striking deep in heavily protected waters became the hallmark of the submarine.[16]

The battle for the North Atlantic during WWII illustrates not only the development of submarine signature control, but does so in the context of the sensor that has proven very difficult to impair or defeat, radar. The effort to reduce the effectiveness of radar also illustrates the history of the action-reaction cycle, a characteristic of all weapons and counters development. Following the U-Boats' initial success in sinking Allied shipping, the Allies were able to severely degrade U-Boat operations by employing land-based long range maritime patrol aircraft to catch U-Boats operating on the surface while recharging their batteries. Many of these initial detections were visual. The German Kriegsmarine fought back by developing the snorkel, a device that allowed the submarine to recharge its batteries just below the surface. Visual detection was avoided and stealth characteristics were restored. The Allies, in turn, developed an airborne radar that could detect the snorkel. The Germans then responded by developing a rubbery coating

(currently called RAM) that they used to coat the snorkel. This degraded the effectiveness of the airborne radars and continued to drive the cause-effect cycle.

Early RAM.

RAM was used in many ways, including absorbers for radar test chambers and applied to ship's masts for the purpose of preventing their interference with on board search and fire control radars.[17] As indicated previously, RAM was used to reduce the signature of U-Boat snorkels. It was developed under the Schornfeinsteger (chimney-sweep) code name.[18] The U.S. was not far behind. A U.S. Massachusetts Institute of Technology (MIT) team developed "anti-radar paint"' designated MX-410, in 1945. It was a rubber material imbedded with plate-like aluminum flakes. The results were invariably disappointing. The trial and error process was necessary because techniques for analyzing the RCS of complex real world objects had yet to been invented.[19]

A number of 1960's drone projects capitalized on their already small size by using various kinds of RAM to reduce their RCS. They include Ryan's Q-2 Firebees, Model 136, Model 147, and AQM-91 Compass Arrow, North American's AGM-28B Hound Dog air to surface missile, and Lockheed's D-21 (launched initially from an A-12). The advantages of LO were understood, but the means were not at hand.[20] As previously described, it takes a 10-fold reduction in RCS to begin to produce improves survivability.

Acoustic Signature.

The U.S. Army lays claim to the first fielded operational stealth aircraft. Developed for use in the Vietnam war, the Lockheed YO-3A was utilized for night observation.[21] Lockheed built fourteen YO-3As, in response to a Defense Advanced Research Projects Agency (DARPA)

originated requirement, based on a Schweizer sailplane which focused on quieting an inherently small RCS platform (based on its small size). This was the first manned combat aircraft that was designed to rely on stealth, using a highly muffled engine to hinder acoustic detection .[22]

Synthesis of Motivation, Theory, and Enabling Technologies

Clear Motivation.

Ever since radar systems were fielded, planners thought that surprise attacks were rendered null and void. The legacy of the IADS was the development of the technology, tactics, training, and strike package integration that allowed penetration of the air defenses and accomplishment of the mission while sustaining acceptable losses.[23] This is a clearly defined mission need. No anti-radiation missiles, no specialized defense suppression assets and few jammers were available in 1965. The ARMs were new but the defense suppression assets were all hastily reinvented after their initial introduction during WWII and deployed in the 1966-67 time frame as a response to the ever increasing losses to radar directed SAMs and AAA.[24] In some respects the USAF had regressed from the EW capability it enjoyed at the end of WWII. To address the current need during the Vietnam War, the USAF developed a technique of constructing a large package of aircraft to simultaneously overwhelm the defenses while using various support aircraft to degrade or destroy specific defense capabilities. Support aircraft proliferated in an effort to address the radar guided SAM threat arrayed against the two Linebacker operations during 1972 in Vietnam. Fighter escorts, chaff bombers, B-66 jammers, F-105 Wild weasels carrying missiles that homed on a threat radar's emissions were integrated into strike packages. Although package tactics were successful, it became clear that small changes in the technological balance could result in a dramatic change in combat effectiveness. The overall

level of concern was heightened by the fact that the Soviet IADS was believed to be a more difficult challenge than the Vietnamese defenses.[25] Package tactics increased survival, but resulted in only a relatively few aircraft actually attacking the target.

The October 1973 war, the Yom Kipper War between Israel and Egypt, was not a rerun of the Israeli air successes of the earlier June 67 War.[26] The SA-6, a new and improved SAM, upped the ante in 1973. It was so successful that Israeli ground forces had to be used to clear the SAMs before the Israeli Air Force (IAF) could operate without excessive losses.[27] The IAF lost 109 aircraft in 18 days, mostly to radar guided SAMs and AAA. While it boiled down to a confrontation between U.S. designed aircraft (Israelis) and the Soviet IADS (Egyptian and Syrian), it also highlighted the effectiveness of the IADS and the complexities associated with defeating it.[28]

In 1982 the Israelis went to war with a combat air force still remarkably like our own. Their victory was quick and clear, achieving an aerial combat score of 89 to 0 using F-15s, F-16s, and Airborne Warning and Control System (AWACS) surveillance aircraft. The IAF suppressed surface-based SA-6s and SA-8s with almost no losses using virtually the same equipment used by the USAF.[29] What had changed? Superior equipment, F-15s, F-16s and AWACS replacing F-4s and ground radars, and weapons, anti-radiation missiles, employed in conjunction with decoys further advanced the science of package development and wrested the advantage back from radar for the moment.

A new technology, spawned as a result of the IADS challenges, took additional time to bring to fruition. This technology initially gained the general public's attention in 1989 when the F-117's debut was highlighted by its use during the Panamanian Just Cause operation. Stealth

and precision have combined to significantly enhance the effectiveness of small numbers employed in precise raids.[30] It would also allow penetration of the IADS with an acceptable survival rate. However the overarching objective driving the development of stealth technologies was not limited simply to penetrating the IADS, but the nullification of 40 years of Soviet IADS development.[31] The pursuit of stealth capabilities, at substantial expense and with considerable risk, had potentially far reaching implications. One of those implications would be the direct challenge of the Soviet IADS, and by extension, Soviet military security.[32]

Contemporary stealth development began in 1975 and was driven by the complexity of the Soviet IADS that had deployed at least fifteen different complementary SAM systems. As is the case with many weapons developments, it was a classic case of a technology and counter technology, radar measure and countermeasure, race played without end.[33] In this case it was primarily radar and associated weapons versus counter radar technologies and tactics.[34]

Before the advent of stealth, the preferred means to contend with the IADS was avoiding the radar net by flying below it. Penetrating aircraft such as the F-104, F-111, FB-111, and the Tornado were designed to underfly radar coverage as a means to increase survivability.[35] The B-1A, flying at treetop level, was to be the U.S. solution to penetrating the IADS.[36] In 1978 the Undersecretary of Defense for Acquisition, William Perry, was convinced that a stealthy deep penetration bomber would give the U.S. air supremacy over the Soviet Union for at least a decade.[37] It was also becoming apparent that the B-1 would take excessive losses while penetrating the Soviet IADS at low altitude.[38] The coincidence between the availability of the results of the first stealth aircraft, one of the two stealth prototypes (code named the Have Blue), RCS testing and the cancellation of the B-1A, which subsequently became a major presidential

campaign item, suggests that both the vulnerability of the B-1A and the future availability of a viable alternative played a key role in the cancellation decision.[39] When the B-1A was reincarnated as the B-1B, its RCS had shrunk to approximately 1% of the B-52's or a one hundred-fold reduction.

Theory.

The seed for a stealth aircraft design was planted in the same way in which the pre-WWII seed for radar technology was planted, exploitation of foreign theoretical scientific work. In 1975, a 36 year old radar specialist by the name of Denys Overholser who worked for the Lockheed Advance Technology Division, popularly known as the Skunk Works, read a recently translated 1966 Russian technical paper titled, "Method of Edge Waves in the Physical Theory of Diffraction," by Pyotr Ufimtsev.[40] The paper, built on the earlier work of James Clerk Maxwell, a Scottish physicist, developed equations that could predict how a body of a specific (simple) shape would scatter, or reflect, electromagnetic radiation. It outlined a technique that explained how to accurately calculate RCSs across the surface of the wing and at the edge of the wing and put together these two calculations for an accurate total.[41]

In other words, this revelation meant that, for the first time, RCS could be accurately predicted and an economical design process could begin. Ufimtsev had shown us how to program a computer software to accurately calculate the RCS of a given configuration, as long as it was in two dimensions. Complex shapes were too difficult to address until advanced computer processing capabilities became available.[42] In 1975 a Skunk Works engineer, Bill Shroeder, designed a controllable aircraft that made use of simple shapes, flat surfaces, that allowed RCS to

be both modeled and predicted accurately. This technique ultimately became known as "faceting" and was applied as the key RCS design element of the F-117.[43]

Enabling Technologies.

Computers in 1975 simply were not yet sufficiently powerful in storage and memory to allow for RCS computations or predictions, which demanded enormous numbers of additional calculations.[44] The advancement of a number of computer core technologies had the affect of enabling the development of stealth. Computer expansion facilitated the solving of the vast number of equations required to be able to predict radar signatures. These powerful design computers enabled the complex multivariable analyses of radar returns as a function of aspect, geometry, reflectivity, and structural properties. Only after this advancement occurred did the development of stealth aircraft become feasible.[45]

Computer speed and processing volume also figured in the development of a "fly by wire" flight control system, a system that is absolutely necessary to control the unstable platform designs necessitated by early stealth airframe shapes. Stealth not only required computer advances to enable its design, but required some of those same advances to enable its effective employment. Increases in processing volume were necessary to allow the vast number of calculations necessary to determine the optimum path around and through known enemy defenses. The mission planning systems designed to do this are highly dependent on a large computational capability. Therefore significant computer developments, including computational volume and speed, were precursors to the development of stealth designs and mission planning systems.

Greater reliance on threat data is a characteristic of the stealth mission planning process. Mission planning allows the optimum employment of stealth assets by determining the best path

through the defenses, effectively increasing survivability by decreasing the platform's vulnerability against known threats. This reliance then requires a substantial investment in the collection and timely dissemination of IADS intelligence. The stealth derived requirement to obtain, transmit, and process mission planning data in real time became a related challenge.

In marked contrast to openly funded programs, it took just days to set the F-117 program into motion.[46] The Director of the Skunk Works, Ben Rich, convinced senior Pentagon authorities that a stealth design was possible and DARPA agreed to fund a technology demonstration in 1976.[47] It was clear that the IADS motivation had already been established. Have Blue was conceived as a near term technical demonstration and as such made use of many off the shelf components.[48] The diamond shaped design, beveled in four directions, that was to become the F-117 took just five weeks and was ready on September 14, 1975. Limited access reduced the affect of bureaucracy and the use of off the shelf components resulted in Have Blue's first flight in early 1978. Subsequent tests confirmed that the design was predictable and demonstrated a tactically effective RCS. The tests also proved that, much like the conventional F-16, an inherently unstable stealth aircraft could be controlled with a fly by wire system.[49] The resultant RCS reduction was characterized as "not the size of an eagle, but the size of an eagle's eye." The Have Blue success led to the Senior Trend project, which got the go ahead in 1978.[50]

Stealth engineers had to face a number of challenges to the currently accepted design solutions. External ordnance and fuel tanks had to be eliminated to achieve the desired RCS.[51] Maneuvering was a secondary priority to that of RCS.[52] Having demonstrated the capability of a flight control system, the next challenge facing the flight control engineers was how to reduce the RCS of the pitot static system, a group of tubes or probes that provide the pressure and angle of

attack data necessary as inputs to the flight control system.[53] From the very beginning the design included a complementary low infrared signature, achieved by the elimination of afterburners and the use of baffles and quartz tiles to reduce heat signatures.[54] Engine and exhaust noise absorbers reduced audio emissions while the elimination of a onboard radar made a major contribution to the extensive control of all electromagnetic emissions which could highlight an aircraft that relied on stealth for its effectiveness.[55]

The F-117 was conceived black, built black, and intended to fly (train) and fight black. This was a difficult level of access to control because of the aircraft's distinctive appearance.[56] The F-117 program was declassified on November 1988 which considerably reduced the difficulties associated with planning and training.[57] Its best use was initially believed to be employed as a platform for Special Operations Forces (SOF) to use in situations where responsibility could not be reliably traced. In other words, no demonstrable proof of guilt or "smoking gun."[58] The F-117 could penetrate with high survivability, deliver extremely accurate ordnance, and return with a video tape that provide excellent battle damage assessment (BDA).[59] Stealth technology was applied to gain and hold the element of surprise.[60] The F-117 made its public debut a Nellis Air Force Base on April 17, 1990.[61]

The Process

The motivation to solve the IADS problem was immense. The issue was fresh in our minds, resulting from experiences in both the Vietnam and Yom Kippur wars. Doubts about the U.S.'s capability to penetrate the IADS, combined with the perceived Soviet capability to carry out a preemptive nuclear attack, enhanced the feeling of U.S. vulnerability. Recent advances in computer capability enabled the process in three ways: provided the computational muscle to

solve the RCS equations; supported the ability to fly an unstable design through a fly by wire system; and developed the necessary software and storage elements to tackle the three dimensional mission planning problem. On board computers were used to achieve aerodynamic stability. They executed virtually thousands of tiny electrohydraulic adjustments every second and transmitted them to an aircraft's control surfaces. In this way the computer compensated for an inherently unstable aircraft design. This enhanced computerized flight instability allowed the latitude for designing the small wings, short tails, and mini-wing flaps necessary for effective stealth shaping. This left the enormous problems of unstable pitch and yaw for the computer to solve.[62]

While the IADS challenge provided the motivation, information, as inadvertent crossflow (from the Russian technical community) and computer processing developments had established the enabling foundation for stealth. The fortuitous merger of a Russian theoretical concept and advanced computer technologies, under the threat of the IADS and in the hands of an innovative organization produced the stealth breakthrough. This summary of the stealth's development components for success does not appear to be the organized process called for in General I.B. Holley's book, *Ideas and Weapons*.[63]

In the process of building Have Blue, the Skunk Works employed a number of strategies that are currently part of the Quality Air Force program. They include: making use of numerous off the shelf parts to save money; the use of a small number of talented individuals organized in an integrated interdisciplinary structure that empowered the employee across a broad range of tasks while constantly looking for manufacturing and performance improvements; and designers and engineers that stayed close to the production floor, working in interfunctional groups.[64] A direct

span of control, relatively independent from the corporate hierarchy and close continuous collaboration with the customer allowed the development of an innovative and efficient operation.[65] During the F-117 program, there was a very close and trusting relationship between the customer, the government, and industry. This allowed the application of formidable technical skills around the clock in very practical ways.[66] The intimate working relationship between the builder and the user was key to the magnitude and speed of the development.[67]

Using the same lean organization, the automated mission planning system was developed in a 120 day period at a cost of $2.5 million. This system used two powerful computers to analyze every aspect of a mission and applied the latest satellite and other source acquired information. This allowed the avoidance of the most dangerous threats and was detailed enough to determine the exact bank angle for the fighter to turn at in order minimize detection.[68]

Manufacture.

It took just 22 months to build the first F-117.[69] The F-117 started testing on June 18, 1981 with the flight of the first prototype.[70] It took five years to build an operational squadron of eighteen F-117s whereas it took ten years for the first F-18 squadron to come on line.[71] The F-117 was declared initially operationally capable (IOC) in October 1983.[72] The relatively rapid deployment mirrors the speed with which Britain deployed its radar defense system prior to WWII. This was accomplished even in the face of new and demanding manufacturing techniques such as faceting. Faceting is a rigorous discipline which requires perfect edges to obtain the desired result.[73] Manufacturing techniques were developed specifically to work with the new materials and high tolerances required.[74]

One of the biggest manufacturing challenges was to develop the processes required to produce and apply the new RAMs. Various RAMs had fundamental strengths and weaknesses that had to be modified and combined to meet the desired signature specifications without degrading the airframe strength. Materials that allow radar waves to pass through are actually transforming those waves into heat which must be dissipated or absorbed.[75] A perfect RAM does not exist - capabilities vary by frequency and the angle of incidence of the incoming beam.[76] Materials imbedded with magnetics work best against low wavelength radars, such as the older VHF and UHF radars.[77] Dielectrics are optimized at microwave frequencies, used by most modern radars.[78]

The Skunk Works produced two aircraft per month with an astonishing 78% learning curve (over twice the normal rate), evidence of its result oriented quality approach.[79] The cost of the 59 aircraft produced amounted to $6,560.3 million. The research and development bill was $1,999.6 million and the aircraft spares and equipment amounted to $4,265.3 million for a total program cost of $12,514.6 million. They were ultimately produced at a rate of eight per year for a flyaway cost of $42.6 million per aircraft.[80] This compares with $50.4 million for an F-15E, built totally in the white during the same time period.[81] Neither building small numbers of nearly hand crafted machines in the black world or incorporation of significant new stealth technologies seemed to dramatically differentiate fly away costs. Stealth proved profitable as Lockheed turned the breakthrough into a six billion dollar fighter program, earning at least eighty million dollars in profit.[82]

Other Applications.

A picture taking session of a stealth model resulted in the discovery of a potential counter sonar application. The fuzzy pictures were traced back to the sound echo auto focus system, a device which operates similar to sonar, that had been fooled by the RAM coatings. A quick test showed a three order of magnitude (ten times) reduction in sonar returns.[83]

Stealth techniques had been recently applied by the British Royal Navy during the Falkland Islands campaign. They had achieved some success at reducing the RCS of selected ships by draping primitive ferrite-coated nets over the masts and radars. This technique was potentially much more valuable, so the concept of a stealth ship, focusing on avoiding detection by Russian radar satellites, was born.[84] Testing highlighted the fact that being invisible to radar could, in fact, give away a position by displaying nothing where a steady state background (wave tips in this case) should be present. A blank spot among a background of wave tip returns thus became a dead give away.[85] Although the resulting concept ship, called the Sea Shadow, was not pursued by the Navy, the technology developed was applied to a new class of destroyers as well as to submarine periscopes. Stealth techniques and doctrine continue to be intimately related to submarines and their mission.

Unfortunately, the opportunity to develop design and production talent that made the F-117 program a success may be considerably limited in the future. In the middle of the 20th century, a career aerospace engineer may have worked on over 20 designs. A new engineer in the same business may only get the opportunity to work on one.[86]

The level of secrecy demanded by the USAF limited the drag of the massive Defense Department bureaucracy, but forced the establishment of an extensive security organization.

Stifling security inspections followed by the required bands of Occupational Safety and Health Agency (OSHA) inspectors caused tremendous inefficiencies, even in the bureaucracy-reduced black world. The doubling of the contractor's administrative staff was just one legacy of this requirement.[87] These black world security aspects must be balanced in order to bring new technologies to timely fruition. However even with the security drag, this organization was amazingly efficient, taking only twenty months from contract award to the first Have Blue flight, December 1, 1977. This was followed by two years of flight test which generated the data for finalizing the F-117 design.[88]

Development to Application

A well defined mission need, exploitation of adversary theoretical work, innovative application of fundamental research, a credible and aggressive entrepreneur, advancements in supporting technologies, and black world program administration all contributed to the successful initiation and development of stealth technologies in the U.S. How did the actual F-117 development process compare with the path prescribed by the formal acquisition system? What was doctrine's role in this process? Can this path be retraced again for another technology? The apparent unsystematic convergence of all of the required components of this effort suggest that the acquisition process is more unsystematic than desired. The historical record suggests that the development of technologies and their subsequent application should be considered separately. The wandering of the acquisition system, however, did not reduce the impact of stealth technologies on the battlefield where the success of stealth in combat was clearly demonstrated.

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[83] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 272.
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CHAPTER 5 -- RESULTS

Stealth, as an applied technology has passed a major test of effectiveness at the individual aircraft, tactical, and operational level. Entering service in 1983, stealthy F-117 came of age during the Gulf War, achieving precisely what it was intended to do. The time between fielding and employment was spent productively preparing for its utilization. That preparation allowed it to evade the most capable of air defense environments and boldly attack and destroy key hardened targets while sustaining no losses. The F-117's destruction of Iraq's air defense headquarters, sector air defense centers, and key air defense infrastructure dramatically enhanced the survivability and effectiveness of other weapons systems. Stealth is the primary factor that allowed the transition from an air campaign that rolled back enemy defenses incrementally, one layer or section at a time, to a simultaneous attack approach that resulted in the early establishment of air superiority and then supremacy.[1]

Stealth's Contribution

Harold Brown, the Secretary of Defense from 1977-1981, summed up the F-117 program when he said: "The F-117 illustrated the combination of a workable doctrine and operational concept -- combining the airplane's invulnerability with high precision bombs."[2] The stealth breakthrough had two significant impacts: It changed the way that air wars will be fought from now on and; nullified the tremendous Russian investment in their IADS.[3] The U.S. essentially produced the most significant advance in military aviation since jet engines, while rendering null and void the enormous 300 billion ruble investment the Soviet's had made in missile and radar defenses over the years. The means to counter stealth were beyond current technology,

demanding unreasonably costly funding and the creation of new generations of super computers at least 25 years off.[4] In the words of former Secretary of Defense Casper Weinberger (1981-1986), "The stealth program was a classic example of a research and development triumph of historical proportions. Stealth canceled all the dimensions and equations for planning future air campaigns."[5] What was first designed to cope with Soviet SA-5s and 6s, or to open the door for the attack fleet, has proved much more versatile than originally expected. This initial role, rather limited and myopic, illustrates the requirement to develop appropriate doctrine in order to exploit all aspects of a given technical breakthrough.[6]

The F-117 turned out to be an excellent example of applied technology. It was not only reliable, maintainable, adaptable, and appropriate to the tasks at hand,[7] but its blend of technologies and utilization represented a synergy that has been seldom experienced. Although the F-117 was employed in Panama, the reason for its use was based solely on its precision capability. Precision and stealth were used together for the first time in the Gulf.[8] First, pairing the stealthy capabilities with an on-board precision weapons system, that included the ability to penetrate hardened targets, mutually enhanced the effectiveness of each individual technology. Stealth characteristics vastly decreased the vulnerability associated with the normally high risk requirement of providing stable laser energy on the target during the bomb's time-of-flight.[9] The reduction of detection range provided by stealth may benefit the aircraft in other ways. If equipped with a passive detection system, it will be able to detect hostile radar transmissions long before the source radar can detect the stealth aircraft. This ability to detect the threat, combined with an aircraft's inherent ability to maneuver to avoid it, creates a difficult defense problem. The

capability to determine the enemy's location before detection applies to AWACS aircraft as well as ground emitters.[10]

The F-117s acted as enablers or enhancers of other systems.[11] They increased the effectiveness of non-stealth platforms by degrading the IADS through precision attack, relying on the inherent survivability features of stealth to increase the availability of specialized support assets for other platforms. Stealth requires much less power output from active jammers to distort adversary's radars. Burn through ranges decline much more rapidly with RCS than the detection range will. The use of stealth technologies, even in small quantities, enables much more effective active jamming using lighter, simpler, and less power hungry EW suites.[12] This capability allowed the dedicated electronic warfare aircraft to refine their focus, playing a central role in the neutralization of the Iraqi IADS and providing some of the most dramatic successes of the war.[13] The subsequent reduction of the overall requirement for support assets had the effect of force multiplication on at least two levels. It allowed the existing support assets to be used more effectively in the support of non stealthy platforms and thereafter increased survivability and productiveness of those conventional assets. Increased survivability and more productive missions expanded the operations tempo and improved the overall efficiency of the campaign.

Desert Storm: Combat Proven

Doctrine.

The entire tactical system, the assembly of force packages escorted by specialized Suppression of Enemy Air Defense (SEAD) aircraft, reflected U.S. operational doctrine developed in South East Asia and Europe.[14] Force packaging is not without its difficulties. Each mission requires extensive detailed planning and relies on various intelligence inputs as sources for

IADS deployment information.[15] The key to the IADS driven ever increasing complexity of the force packages was comprehensive planning and synchronized execution. However the large scale planning effort pays impressive dividends. Synchronization--the combining of different capabilities in time, space, and purpose--can vastly magnify the complexity of the problem an enemy must solve.[19] Increased complexity, especially if unanticipated, deepens uncertainty and this makes it more difficult for the enemy to counter friendly advantages well enough to prevent defeat. In fact, the enemy's attempt to counter the complex threat resulting from synchronization may create additional opportunities friendly forces can exploit.[16]

Target categories were shaped at least as much by doctrinal considerations about the proper offensive use of airpower at the operational level of war as by detailed intelligence on targets and target systems in Iraq. In many cases doctrine had to be substituted for a detailed knowledge of Iraq and its associated target sets.[17] The air war sought to disrupt the regime and instill a sense of hopelessness on the front line troops, all in an effort to weaken Hussein's hold on power.[18] Stealth's overall effectiveness contributed to the capability to directly attack military targets with minimal collateral damage, a large change from the technology limited approach used during WWII. This capability allowed terror attacks against the Iraqi people to be categorically rejected and indiscriminate collateral damage to be minimized or avoided.[19]

The gradual escalation concept, tied to theories of diplomatic bargaining stretched out over months, was repudiated with Desert Storm. Decisive blows struck in a timely manner over the short term, now called parallel warfare, were extremely effective.[20] Parallel warfare simultaneously attacks the enemy center of gravity to achieve strategic paralysis.[21]

Stealth technologies provided key capabilities that enabled parallel warfare by freeing up assets previously required to execute the packaging doctrine. Stealth is but one means, although a critical one, to these ends. The success of parallel warfare and the application of doctrine during Desert Storm highlight the importance of each and should motivate us to carefully explore the entire breadth of the weapons development system in an effort to align it with doctrine development that anticipates and provides for future requirements.

Force Multiplier.

The synchronization of stealth, through the concept of force packaging, established stealth's double-edged sword. The increases in survivability accorded by stealth allow these systems to be employed without the sophisticated support packages developed to confront the IADS. This allows precious support assets to be used for parallel tasks.[22] Even while freeing key support assets to support non-stealth platforms, the F-117 for example, acts as a force multiplier for those packages by destroying key components of the IADS subsequent to an attack packages ingress and attack. This optimum utilization of stealthy assets provides a logarithmic increase in "bang for the buck." Just as signature control contributes to all the tenets of air power, it not only makes additional assets available for assault package construction, but significantly increases the survivability and effectiveness of the package by degrading the IADS arrayed against it.

Proof Required.

The systematic development of the technologies deployed in Desert Storm reflected a continuation of the successful trend started in WWII, where the U.S. had been successful at anticipating the increasing importance of individual weapons capabilities and planning for the timely development of selected technologies.[23] As outlined before, the combination of

technology, application and doctrine came together in Desert Storm. However, even the development of an effective doctrine will not totally erase the uncertainty associated with a technology that has not been combat tested and proven. The proof that succeeded in convincing the pilots, on the eve of their full scale combat debut in Desert Storm, was watching the bats, that made their home in Saudi Arabia's reinforced hangers, crashing into the tails of the F-117s. If the technology was good enough to fool the bats, then the Iraqis must also be vulnerable.[24]

The IADS that protected Baghdad had seven times the density of the system that protected Hanoi during Linebacker II. The penetration of Baghdad's air defenses, even denser than the most heavily defended eastern European target during the height of the Cold War, were left to the F-117 and cruise missiles. Coalition air power destroyed the IADS using the F-117, aircraft employing anti-radiation missiles and a vast array of electronic measures.[25] The *Gulf War Air Power Survey* states it best:

> "On the first night of the war, an elaborately choreographed combination of stealth aircraft, specialized electronic warfare aircraft, decoys, cruise missiles, and attack aircraft delivered a sudden paralyzing blow to the IADS from which the Iraqis never recovered."[26]

The Combination of Stealth and Precision.

The initial F-117 targets in Baghdad included hardened air defense sites and critical command and control centers, targets that prevented the IADS from effectively engaging the non-stealthy platforms.[27] On the first day of the air war, the F-117, comprising only 2.5% of all the fighter and attack aircraft in the theater, attacked over 31% of the strategic targets. This trend asserted itself throughout the campaign with the F-117 using 2% of the total combat sorties to attack 40% of the Iraqi strategic targets.[28] The F-117's effectiveness is illustrated by the fact that

79% of the 2,041 tons of bombs (1,616 tons) delivered in 1,270 combat sorties hit their targets. A hit was defined as an impact within 10 feet of the aim point.[29] Although hits do not equal kills, this impressive figure of merit did translate into a substantially higher percentage of targets destroyed. Stealth, when combined with precision guided ordnance, has dramatically increased the efficiency of air power.[30]

It has also increased the survivability. Destruction of the Iraqi IADS resulted in an attrition rate for coalition aircraft that was less than a tenth of that incurred by the U.S. over North Vietnam. During the Linebacker II operation, 18 to 29 December 1972, the U.S. lost twenty-five aircraft out of about 3200 combat sorties, compared to thirty-eight losses out of about 70,000 sorties in the Gulf War.[31] The F-117's performance came as a complete surprise to almost all observers and proved nearly impervious to Iraqi defenses. It also required minimal support from other aircraft.[32] The U.S. capitalized on that fact in Desert Storm, combining assets to demonstrate an excellent example of optimum force packaging.[33] Increasing the efficiency of air power while significantly improving its survivability makes stealth a very powerful tool.

Stealth's Effectiveness

The Legacy of Stealth.

Stealth is wonderfully economical. It reduces support sorties, diminishes vulnerability to detection and interception, and makes a remarkable impact in the computation of overall life cycle costs.[34] Enhanced survivability is a boost. With stealth, F-117, B-2, and F-22 pilots can identify with Winston Churchill's quote, "there is nothing more exhilarating than to be shot at without result." During Desert Storm, the Joint Forces Air Component Commander (JFACC) used his forces to strike the enemy, across the length and breadth of his territory, on the first night with no

losses among the attacking F-117s. The air supremacy that stealth helped to achieve, a product itself of parallel warfare, allowed the Coalition to strike the enemy with near impunity.[35] Survivable platforms with precision weapons command decisive force and wield it in a highly compressed period of time, but their effectiveness does not stop there. Their enhanced ability to provide battlefield damage assessment (BDA) is another major contribution to their overall contribution.[36]

The importance of feedback, including target identification, attack method, and primary and secondary results, is critical to the target selection and revisit decision process. Stealth, by limiting a platform's vulnerability, facilitates real time feedback and timely analysis.[37]

Focus on Command.

It is imperative to remember that all actions are aimed against the mind of the enemy command. According to John Warden, "this is the essence of war."[38] In order to accomplish this goal, pressure must be applied against the adversary's innermost strategic ring, its command structure.[39] The focus of war operations is most effective when centered on the enemy leadership.[40] The F-117 made simultaneous attacks on nearly all the major air defense nodes, the Iraqi AF headquarters and air defense operations center in Baghdad, most of the country's sector operations centers and their accompanying intercept operations centers, and even some forward radars. As a result of the first ring attack on communications and the second ring attack on electricity, the Iraqi high command was instantly rendered blind, deaf, and dumb. No possibility of coordinated air opposition to the subsequent attack of non-stealth aircraft could be mounted. Every shooter, fighters, SAMs, and AAA, was driven into an autonomous mode.[41]

The Coalition then proceeded to impose strategic paralysis on Iraq with just over 10,000 sorties and just over 20,000 tons of bombs. Compare this 20,000 tons of bombs with the over eight million tons dropped on Vietnam in seven years and the 200,000 ton dropped on Germany's oil refineries over a twelve month period during WW2.[42] The Coalition forces had dropped fewer that one percent of the bombs dropped during the Vietnam war.[43] Coalition effectiveness was enabled by the F-117s and exploited by the doctrine of separating the Iraqi command structure from both intelligence inputs and execution outputs.

A note of caution is appropriate here. Only the adversary can define defeat and ultimately decide when it occurs. The challenge then becomes attempting to look into the enemy's mind and forecast his definition of defeat and then determine what actions can have an effect on that decision process. Even though John Warden's five ring system model accommodates this fact, it is extremely difficult to determine an adversary's definition of defeat.[44] It is the enemy leadership that ultimately decides to accommodate you.[45] Stealth cannot select targets, but it can be useful in affecting those that are identified as being critical to the defeat decision process. The Gulf War does, however, illustrate the fatal consequences of losing strategic air superiority -- a country that cannot defend itself eventually loses hope.[46] This vulnerability is tied to the defeat process and can certainly be exploited through the application of stealth capabilities.

Surprise.

Both operational and strategic surprise were gained through the application of stealth technologies.[47] Stealth brought tactical and operational surprise back to air warfare. In the first minutes of the Gulf war, without giving any useful warning to Iraq, F-117s struck a large cross

section of critical targets.[48] In many ways, we were catapulted back to the days before radar, when enemy aircraft were parked in the open.[49]

Stealth Applied.

Stealth is the most important military aerospace technology since the invention of radar in World War II. Like radar, stealth would change the way that all subsequent air wars would be fought.[50] As identified in the Air Force's *Global Reach----Global Power* White Paper, speed, range, flexibility, precision, and lethality are the five unique characteristics or tenants of air power.[51] The enhanced survivability of a stealth platform clearly affects all five tenants. Signature control either adds, augments, amplifies, or acts as a multiplier to these characteristics. Stealth allows more direct target routing which in turn extends range and decreases time enroute. The ability to neutralize enemy defenses allows the pilot to focus on the weapons delivery phase which in turn supports improved precision which leads to increased lethality. Precision weapons, in conjunction with a stealth platform, made it possible to achieve maneuver, mass, and concentration on an entirely unprecedented scale.[52]

Stealth capability, used in the form of the F-117, proved convincingly that signature control technology not only exists, but works. This demonstration of stealth's effectiveness virtually guaranteed that all designers of future aircraft will attempt to incorporate signature control techniques in their designs. Future designs will be focused on minimizing the F-117's performance, cost and supportability limitations while improving or preserving its signature control characteristics.[53] The F-22 design demonstrates the successful application of that design philosophy. Rarely does a single set of technologies have such a significant across the board impact.

The Employment Doctrine was Successful.

Technology can not stand on its own. It is not a substitute for innovative tactics and a sound strategy. Stealth is important, but it was the way in which the coalition forces were deployed and coordinated, that more than any other factor, determined the outcome of the Gulf conflict.[54] In the case of the Gulf war, technology -- which reinforced the discretion we allowed our soldiers and airmen -- was combined with individual initiative to build an effective, flexible fighting force that Saddam Hussein could not withstand.[55] The Desert Storm experience further illustrates both the successful doctrinal employment of stealth and the need to continue to develop and exploit doctrinal development.

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[1] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 245.
[2] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 344.
[3] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 65.
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[6] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 98.
[7] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 242.
[8] Donald B. Rice, "Global Reach--Global Power The Evolving Air Force Contribution to National Security," *AWC Department of Military Studies Readings: Book 2 Military Studies Course--MS 610*, ed by Col Bryant P. Shaw and Dr. William P. Snyder, (Maxwell AFB, AL: Air University, June 1994), p 299.
[9] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 226. Note: The predictable flight path during target illumination, or designation, is a major factor in increasing the vulnerability of non-stealth platforms to ground defenses.
[10] *Bill Sweetman, Stealth Bomber Invisible Warplane, Black Budget, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1989)*, p 155-156.
[11] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 348.
[12] *Bill Sweetman, Stealth Bomber Invisible Warplane, Black Budget, (Motorbooks International Publishers & Wholesalers Inc.: Osceola, WI, 1989)*, p 157.
[13] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 195.
[14] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 220.

[15]Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 167. Note: As for individual tactics, stealth fighters employ as single ships against specific point targets. Using the tactic of threat avoidance, based on the utilization of reduced signatures to compress sensor detection ranges and mission planning based on IADS intelligence estimates, the F-117s thread their way through the IADS like an adult avoiding puddles (a child would make every effort to hit the puddles) on the way to work. The puddles, representing the range capabilities of individual SAMs, are made smaller by reducing the target's RCS. As the puddles become smaller, they become easier to negotiate and generate additional routing flexibility. The "puddle" analogy is an important tool in understanding what stealth capabilities bring to the table.

[16]*Basic Aerospace Doctrine of the United States Air Force*, (Air Force Manual 1-1, Volume II, March 1994), p 130. 19 For a treatment of synchronization, see Gen William E. DePuy, "Toward a Balanced Doctrine," *Army*, November 1984, 18-25.

[17] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 137.

[18] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 43.

[19] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 46.

[20] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p219.

[21] John R. Prado, Jr., "Parallel Warfare Its Nature and Application," *Challenge and Response Anticipating U.S. Military Security Concerns*, ed by Karl P. Magyar, (Air University Press, Maxwell AFB, AL, Aug 1994), p 277.

[22]Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 153.

[23] John F. Guilmartin, Jr., "Technology and Strategy; What are the Limits," *Two Historians in Technology and War*, by Sir Michael Howard and John F. Guilmartin, Jr., (Strategic Studies Institute, U.S. Army War College, U.S. Government Printing Office, 1994), p 29.

[24] Ben R. Rich and Leo Janos, *Skunk Works A Personal Memoir of My Years at Lockheed*, (Little, Brown and Company: USA, 1994), p 100.

[25] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 41.

[26] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 230.

[27] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 169.

[28] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 174.

[29] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 177.

[30] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 192. A comparison between the level of effort required to disable a single power generating plant during WWII and the Gulf War may be useful. It would take 108 B-17s dropping 648 1,100 LB bombs to guarantee a 96% chance of getting two hits required to do the job. A single F-117 delivering two laser guided 2,000 LB bombs improves on that percentage. The B-17s were crewed by 1,080 airman compared with the F-117's single pilot.

[31] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 229.

[32] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey*, (Maxwell AFB, AL: Air University), p 224.

[33] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War*, (USA, Smithsonian Institution Press, 1992), p 153.

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CHAPTER 6 -- ACQUISITION SYSTEM INTERFACE

An acquisition system inherently biased toward producing incremental innovation will not stand up to a changing world order with dramatically expanding arenas for conflict. Both of these developments which call for an acquisition system that focuses on innovative departure instead of evolutionary improvement. The terms "innovative departure" and "incremental innovation" are important because they imply two different approaches to acquisition and development - revolutionary and evolutionary. The following sections attempt to define these terms more precisely and develop a broad understanding of the relationship between technology development and the U.S. acquisition system. Included in this discussion is the identification of the limitations associated with the pursuit of superior technology.

Stealth Revolution?

The employment of atomic weapons on Hiroshima brought a new and overwhelming factor into the relationship between technology and national security. It contributed to the complexity of military challenges and transformed traditional power politics. Superior technological capability, available now and not requiring mobilization, became the dominant power coin of the realm. The military society, which had long resisted the kinds of technological change which might threaten its organizational culture, now rushed to embrace technology and its developmental process.[1] This elevation of technology to an even higher status in the American culture highlights a step in the evolution of the American way of war and necessitates further definition of the relationship between changing technologies and an organization.

Ronald J. Kurth succinctly captured the distinction between "innovative departure" and "incremental innovation," defining innovative departure as disruptive of the existing society. By replacing or rendering obsolete the technology upon which a culture had been based, the culture itself, and the jobs that define it, are put at risk. If the innovative departure is eventually seen as a positive development, it will be assimilated through the less disruptive incremental innovation process. Incremental innovation then is defined as a technological change that enhances, promotes, or more firmly establishes the culture. For this reason, it is accepted with little or no resistance, unlike the fierce resistance expected developed by innovative departure.[2] The terms innovative departure and incremental innovation are one means of getting to the crux of the conceptual differences between revolutionary and evolutionary technology development.

We are surrounded by authors declaring revolutionary breakthroughs, espousing the Military Technical Revolution (MTR) or citing the transition to the Revolution in Military Affairs (RMA). Whereas the MTR was used to describe dramatic changes in the conduct of warfare driven by rapidly advancing technology, its follow-on concept, RMA, focuses on the operational concepts, organization and doctrine of the forces employing capabilities generated by the MTR. Although useful concepts, the term "revolution" tends to get trivialized in the process. Sometimes defined as a dialectically qualitative change in the art of war, this subjective definition of revolution is difficult to apply. Applying this definition to the period following WWII, it is not clear if anything, other than employed nuclear weapons, would constitute a revolutionary change.[3]

Some author's have stated that revolutions in firepower and information are ongoing and that a revolution in organizational warfare is just beginning. The RMA, to a certain extent, supports this contention. Regardless of the accuracy of the description of the developing

capabilities in firepower and information. It seems that the most potential for true revolutionary change resides in future organization development. People have vested interests in their organizations and that is where decisive resistance will be encountered. The organization is also where the real impact of radical technologies, perhaps like those in a relatively unexploited medium like space, will occur. True revolutions take decades and require new technologies, forms of organization and behavior.[4]

It is not clear whether or not describing stealth technologies as evolutionary or revolutionary is critical to the ongoing discussion, but in the end the logic demanded to answer that question might prove useful. Using the more workable innovative departure (revolution)/incremental innovation (evolution) construct, stealth would appear to fall solidly in the incremental innovation or evolutionary realm. As has been stated previously, stealth enhances other military capabilities across a broad spectrum. The spectrum extends from reducing the vulnerability of the stealth platform, both by itself and in conjunction with other counter radar efforts, to increasing the survivability of non stealth assets employed on the same operation. Stealth does not threaten the existing culture, but in at least one significant way, by reducing the vulnerability of manned platforms, nearly guaranties the maintaining of the manned aircraft paradigm into the foreseeable future. Stealth and precision are clearly two of a number of evolutionary advances that some believe have combined to synergistically create revolutionary results. The accomplishments of stealth equipped forces in the Gulf War seem to support this belief, but the accuracy of the statement still hinges on the definition of the term revolutionary.

America s Experience With Technology

Throughout history the side with superior weapons almost inevitably succeeded in subduing his enemy.[5] Vietnam is a notable exception. Seemingly ignored for centuries, this fact was finally accepted as a underlying foundation of military policy during WWII.[6] In the spring of 1940 a handful of British fighters broke the back of the German aerial invasion because they had an innovation called radar.[7] The successful application of radar to the air defense problem confronting the British was the product of the systematic selection, development, and application of radar, a technology that supported the operative doctrine. Defining objectives or requirements establish the input for the acquisition system. This is exactly the approach the British used in the development of radar. The organization tasked with this responsibility has the critical role of selecting technologies for development that support the operative doctrine.[8] Unlike the British, the U.S. got off to an inauspicious start with its version of such an organization.

As early as WWI, American leaders gained an appreciation for the necessity of wartime technical advantages and the need to systematically maintain that edge in a peacetime environment.[9] The challenge, of course, was how to develop and operate such a system. The U.S. entry into WWI was an example of a country's military moving into the aircraft acquisition process before developing the guiding doctrine. Without an organization that was properly equipped and responsible for the aircraft acquisition task, chaos resulted.[10] The essential characteristic of the U.S. WWI aircraft selection and employment establishment was an organization that based decisions on opinion, technical or tactical, rather than on information or fact.[11] Any effective acquisition system must obtain facts and establish a systematic and objective means to make decisions.[12]

The pre-WWI Board of Ordnance and Fortifications' fumbling response to the Wright Brothers is an enduring example of how an ill conceived bureaucracy can spell the doom of innovative development.[13] When investigating America's inability to get combat aircraft into production during WWI, a subcommittee of the Senate Military Affairs Committee found that the "unsystematic and ineffective" organization had been a drag on production since the beginning of the war. Ill defined, conflicting, and overlapping functions were the culprits.[14] How does this description of the WWI aircraft acquisition system relate to the development of stealth? It highlights the results of not using doctrine to guide the technology acquisition process as well as technology's application to warfare.

Two other air warfare lessons learned from the WWI experience need to be emphasized here. The first concluded that "quality paid better dividends than quantity,"[15] and the "systematic formulation of doctrine is an essential step to successful development of air weapons."[16] The importance of developing superior weapons and the doctrine to employ them can not be understated. Doctrine, however, does not just apply to the successful application of technologies. It must guide in their selection and development as well. Stealth technologies were successfully applied, even though the selection process was suboptimum.

America's experience in WWII highlighted the increasing tactical and operational interdependence of the technologies employed in warfare. The importance of man's role in successful technology exploitation, generally through the innovative development of doctrine, continued to increase.[17] The war experience also convinced Americans that science was essential to the successful prosecution of WWII and would be to future wars as well.[18] This fact further highlights the importance of technology to the American way of war and the importance of

incorporating stealth type technical advances rapidly into the capabilities of the American military machine.

Doctrine's Role in the Acquisition Process

In an evolutionary development world, doctrine should provide critical guidance at the front end of the acquisition system, not becoming an afterthought following development of a system. Doctrine development is expected to follow an innovative departure. I.B. Holly's description of the relationship between doctrine and the U.S. acquisition system deserves some thought. "It [Doctrine] lies behind the decisions as to what weapons will be developed and gives guidance as to the relative importance of several competing roles or weapon systems when the time arrive to apportion the invariably inadequate supply of dollars."[19] Doctrine should guide the technology development process just as it guides technology's employment. The services are doing an excellent job developing budgets, but the input (doctrinal guidance) is deficient, forcing doctrinal issues to be fought out in the budget process, not prior to the process where tremendous efficiencies could be gained. Unfortunately, doctrine development in the U.S. (including the stealth case) tends to lag instead of lead the acquisition system, forcing doctrine to respond to the technologies that survived the budget process, not the other way around. The English longbow went unexploited for 250 years prior to 1346.

In 1346 at Crecy, France, the French lost 10,000 armored knights to the English longbow. Sadly, the French clung to the use of armored knights in battle for another 50 years, at great cost, due to their inability to adopt and/or counter this "revolutionary" weapon.[20] But it wasn't just the longbow that saved the day for Edward III at Crecy, it was the innovative combination of the longbow, supported by Welsh infantry, and a "secret weapon," iron-bound tubes capable of firing

small iron and stone cannonballs.[21] These early cannons and gunpowder were introduced to the Western battlefield against troops in the field at Crecy, yet the battle is famous for the use of the English longbow which is credited with mitigating the three:one odds that benefited King Philip VI's French forces.[22] Alas, the military aircraft development languished for over twenty years in the U.S. after WWI.[23] Doctrine development had not caught up to the technology.

The Acquisition System's Biases

Any military acquisition system tries to manage objectives, plans, and resources. It should develop systems that are designed to perform tasks needed to support a concept of operations (guided by doctrine) that supports specific military strategies and missions. Weapon system requirements should "flow down" from the closed loop military planning process that pursues the establishment of required military response options consistent with existing or developing concepts of operations. The system must do this inside of a framework of strategies and missions that respond to current and potential threats in accordance with national security policy directives.[24] Doctrine should lead the way. Without the guidance provided by doctrine, the acquisition effort becomes fractured and inefficient.

This U.S. acquisition system came under the direct influence of Secretary of Defense, Robert S. McNamara in the mid-sixties. It was designed to use a rigorous quantitative cost benefit effectiveness, accelerated an ongoing trend by subtly inhibiting technological innovation. New technologies could not succeed in a system that required precise measurements backed up by accurate predictions. Pursuit of the unknown did not compete well with established programs in the relatively risk free incremental innovation paradigm. A key metric is cost, but when should costs be considered in the process? If they are considered too soon, innovation is limited. If

considered too late, the program's goals may become too unrealistic.[25] It is no surprise then, that the bulk of innovative designs came out of the black world where the risks could better be shielded from the obtrusive, short term result oriented, and consensual established selection process. Black programs tend to enjoy higher priorities than white programs because their payoffs are judged to be higher. For this reason they employ stringent access limitations which limit the effects of the multiple forces that act on white programs. These are the forces that result in a consensus or compromise instead of a more directed product. High priority and limited access attract top engineers and managers.[26] The U-2, SR-71, F-117, and B-2 are just a few examples of successful black programs.

Black programs can afford to take on the high risks associated with innovative departure by starting small, accepting initial failures, and fielding the best system capabilities to bear, while shedding layers of innovation robbing bureaucracy. The programs are then acknowledged later, at a time that is appropriate for their own situation and characteristics. The F-117, one example of black program flexibility, followed this plan, balancing program exposure with its longevity. This longevity is based on the length of time that the weapons system remains effective (not countered) or period of dominance. The F-117 aircraft was operating operationally for a number of years before the program was acknowledged. Lack of bureaucracy and flexibility are also hallmarks of the black world, not just compartmentalization and secrecy. The established acquisition system, a linear process in a political sea, is reduced to a linear process in a river under black program administration. It is for these reasons that the black world has clearly become the most user-friendly organization when it comes to developing innovative technologies.

Humans are both the prime source of and resistance to change.[27] Embryonic ideas require time to become fully developed for both operational concepts and technology development.[28] The military willingly accepts technical innovations that improve current capabilities, but tends to reject or delay changes that threaten existing organizations, norms, cultures, and interests. Most planners and researchers are charged with, and the established system excels at, producing incremental improvements.[29] The trend is the same for all of the services. The Army's fielding of incremental technology improvements has included numerous current weapons systems: Abrams tanks, Blackhawk helicopters, Patriot missiles and Multiple Launch Rocket Systems (MLRS). The current system succeeds admirably in the development of incremental improvement technologies, but the current security environment combined with dwindling defense resources demands an acquisition system that can produce break-through technologies as well.[30] Acquisition reform has generally been focused on this end, but has been unsuccessful to date.

There are deviations to every norm and the acquisition system is no exception. From time to time entrepreneurs appear to push through technological innovations. They do this by demonstrating convincingly the logical connection between their preferred hardware and more effective ways of conducting armed hostilities. In this regard they perform the function of technology selection and application with a vigor and determination that is uncharacteristic of the established system.[31] The Lockheed Skunk Works, led by Ben Rich, performed just such a function during the F-117 development. These kinds of entrepreneurs encourage innovative departure, but unfortunately the frequency of this action is unpredictable and sporadic.

Pitfalls and Public Support

Stealth technology has particularly influenced the way in which the public views warfare. The American way of war has focused long on air power as a way to use technology to minimize the duration of a war and its resultant casualties. Stealth has allowed long range aerial warfare to become as effective in maintaining public support as in disabling an enemy force. The images that were made available, in place of print media, involving long range photography or fire control system video tapes (the F-117 as a case in point) created an impression of a very sanitary conflict --- of a war almost without human consequences.[32] The military must recognize that the images enabled by stealth have not only the ability to assess battle damage, but also to influence the public's impression of war in general. Given the necessity to gain and maintain the American's public's support to wage war, the consequences of making battle damage assessment images widely available to the public may significantly influence their evaluation of the ongoing events. Stealth technologies provide an example of the potential impact of unintended consequences of introducing a new capability.

At the same time, there is a danger of overselling technology's abilities. Inflated claims can be refuted by both theoretical analysis and various levels of testing. Unfortunately senior Air Force and DOD officials declared that the F-117 is invisible on national television. Although generally descriptive of the capability, the fact remains that the F-117 is not invisible and its level of vulnerability to detection varies based on a number of factors. Credibility is extremely hard to develop and even harder to maintain. There will not always be a convenient war to demonstrate a technology's capability in the only credible test, the crucible of combat.

Grandiose expectations can be as debilitating as false advertising. The one airplane, one bomb, one destroyed target phenomena, first demonstrated in Desert Storm, has the potential to breed a level of heightened expectations that might not be similarly duplicated in other circumstances. The relevancy of each target's destruction must also pass an objective analysis.[33] Both civilian and military leaders should not feed this simplistic exaggeration by over stating or mis-advertising their military capabilities.[34] The exploitation of the technology in question must strike a balance between hopeful predictions and realistic expectations. Nevertheless both the technology and its associated doctrine must be developed and exploited in an optimum manner. A system that can match an innovative environment with realistic expectations will provide the necessary balance. Stealth rules now, but again, the history of development and counter development leads us to believe that counter stealth capabilities will emerge just as counter radar capabilities were developed. Expectations must be controlled so that they do not contribute to the formulation of unachievable goals or unrealistic employment alternatives.

Stealth must pass the ultimate test of every technology: effectiveness over time. Technology has a reputation of overstating its capabilities, understating its risks, and undervaluing its costs. Obviously these kinds of inaccuracies tend to result in flawed cost-benefit analyses. The U.S. strategic bombing campaign of World War II is considered by many to be an excellent example of the phenomenon. Heavy bombers offered a way to win the war without committing massive ground armies. However, the concept relied on the bomber being able to fight its way to the target without significant losses. Although an attractive alternative to a nation with fresh WWI trench warfare experience, the technology available could not support the theory. The capability of the heavy bomber, B-17s and B-24s, to fight their way to a defended target was

untested and then proved to be grossly inaccurate in the skies over Europe. The seemingly lone voice of Claire Chennault, a key air power thinker at the Air Corps Tactical School in the 1930s, identifying the requirement for fighters to escort the bombers, went unheard. The bomber's ability to get to the target was taken on faith, without testing, and proved to be a grave understatement of the risk. Opportunity costs were understated in at least two ways. Neither the costs of the escort force nor the huge ordnance requirements, primarily generated because of bombing inaccuracies, were included in the predicted expense of the heavy bomber force. Realistic expectations are essential to the successful development of innovative departure technologies.

Other Limitations

A number of additional factors must be considered when applying technology to solve the challenges of warfare. Superior technology does not guarantee its effective use. The way in which technology is applied is key to its success or failure. The British commitment of tanks (before they had adequate numbers or viable tactics) in WWI and the German focus on the fighter bomber (instead of the desperately needed interceptor version) as an application for the jet engine during WWII are both examples of superior technology misapplied in combat. The initial application of stealth technology during Desert Storm was an unqualified success, but nearly all U.S. special capabilities were committed. All of the stealth capability was in the Gulf.[35] The process of applying stealth technology to warfare in earnest has just begun.

Given enough time and adequate resources, technology can be countered, bought, stolen, or otherwise obtained. Technological advantage is a relative thing. Over time it can and will be countered. The technology could turn out to be evolutionary instead of revolutionary, reducing

its span of effectiveness. Moreover, technology does not necessarily have to be countered by technology. Strategy, doctrine, tactics, or combinations of the three can render it ineffective.

Many observers have concluded that air power in the Vietnam War was rendered ineffective by the North's guerrilla strategy. Although superior, the technology available at the time was not effective or appropriate for the guerrilla target base. Advanced technology is difficult to test and predict and may not provide the desired decisive advantage. It may carry unwanted baggage. Costs, training difficulties, and environmental hazards, are just a few of the possibilities. The advantages provided by advanced technologies are fragile, perishable, and elusive.[36] The limitations associated with new technologies have certainly not dampened America's desires to exploit technology in an effort to maintain its war machine's combat edge. They remind us of the importance of human judgment to the technology acquisition process.

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CHAPTER 7 -- FUTURE TRENDS

The new world order and the escalating arenas of conflict are altering the world security environment. New aircraft, with dramatically improved capabilities, are becoming available and new forms of warfare are proliferating. Political options are being developed and expanded to respond to these new conditions. The acceleration of the measure-countermeasure competition shows no sign of slowing down, and as a result, future stealth and counterstealth developments by other countries will combine to provide a challenging security environment for the U.S.

Security Environment

This security environment will have, as a defining characteristic, an increasing number of actors capable of acquiring or producing a range of advanced military capabilities to conduct operations.[1] During the Cold War, our ability to deter a would-be aggressor was determined by the extent to which we were perceived to be able to inflict unacceptable levels of damage. This traditional meaning of deterrence, although not without current applications, has diminished in significance. The world order has changed immensely in the last few years, resulting in the increasing demand for new research and development strategies.[2]

Uncertainties at all levels foster a need for a force structure with the flexibility to respond to a broad range of threats. With numerous uncertainties and unknowns becoming the dominant characteristic of the developing world order, the acquisition process "should place greater importance on weapon systems that can satisfy multirole/multimission requirements against a variety of threats and forms."[3] Technology must be applied across the full spectrum of defense requirements, addressing the need for revolutionary weapon systems as well as incremental

upgrades to existing weapons systems.[4] A weapons system program should provide an essential military response option to cope with multiple threats across the combat spectrum and in accordance with national security policy directives.

The undefined nature of the developing multipolar threat calls for new flexible capabilities and methods of employment.[5] One answer to these challenges is the development of a range of technologies, to include stealth, designed to allow penetration of enemy defenses while minimizing losses.[6]

A central element in developing power projection capability has been superior technology. Both the capability, as embodied in range and lethality, and the survivability, in this case as provided by stealth technologies, are the key and unchanged requirements for the successful projection of power. Stealth makes a significant contribution to power projection capabilities by utilizing its survivability to effectively attain localized air superiority for the time required by the mission. Stealth platforms do not necessarily establish an air superiority that is transferable to non-stealth assets in the short term. However, they clearly fulfill the axiom: air superiority may not be sufficient, in and of itself, to meet the theater commander's objectives, but it is necessary. With it, all is possible -- without it all is at risk.[7] The requirement for stealth and other technologies to assure our retaliatory assets of reaching potential targets will intensify in an expanding air defense capability (counterstealth) environment.[8] Stealth technologies ultimately increase the flexibility of the decision maker by providing highly survivable power projection capabilities.

Stealth's Relationship to New Forms of Warfare

Parallel Warfare.

Stealth's contribution to the implementation of parallel warfare is a key upshot of its effective application during Desert Storm. Stealth enabled hi-intensity operations, designed to stun the enemy and to gain objectives quickly with minimal casualties.[9] Combat simulations have gone even further than Operation DESERT STORM in highlighting the reduction in reliance on mass to accomplish a combat mission. The capability to carry out parallel warfare tends to void the classic force ratio thought process, invalidating the classic three-to-one force ratios deemed necessary for offensive operations. The new dimensions of air combat, including low observable platforms, higher sustained speed, and superior weapons, reduced the influence of numbers on traditional air battles. The concept of a few friendly fighters engaging many adversary fighters began to have no relevance because each friendly could engage many adversary aircraft, but the adversaries could engage only a few friendlies. Stealth so limited the adversaries ability to detect and engage the friendlies that Lanchester's square law (equations describing the attrition of two opposing units) no longer applied. This development effectively results in enhancing the importance of quality over quantity levels in the force mix. Increasing quality's priority has the effect of further emphasizing the importance of seeking innovative departure technologies.

The efficiency and effectiveness of stealth platforms enabled the implementation of a high intensity mode of warfare.[10] Stealth-enabled parallel warfare is another example of a concept that seems to support the premise that multiple incremental innovations can combine to create a innovative departure. The goal of parallel war is to rapidly attack strategic and operational targets, creating paralysis by hitting key targets quickly and maintaining an operations tempo that

denies the enemy adequate repair time while short circuiting his learning cycle. Although a new capability, this approach does not challenge the fundamental military organization.

The question of parallel warfare's revolutionary or evolutionary nature can be explored through its relationship to stealth. Parallel war complicates an adversary's problem by initially saturating his defenses and then maintaining that relative saturation. Although the sustained high operations tempo of parallel warfare is new, it appears to flow directly from the preceding approach, representing evolutionary improvements to the capabilities and concepts that have withstood the test of time. The U.S. Air Force has had a formidable daytime attack capability for a number of years, but by using technology to translate that capability into the hours of darkness and poor weather, it transitioned to parallel warfare. Parallel warfare is an example of technology driving the ever-changing relationship between the offense and defense.[11] The interrelation of radar and stealth technologies provide specific examples of evolutionary technologies trading relative advantages over time. Their dynamic measure-countermeasure competition can be expected to continue to change based on future technological developments.

Information Warfare.

Parallel warfare creates a number of new demands. The emphasis on intelligence is increased significantly. Information becomes the fuel that drives precision, the source of precision's effectiveness. This statement leads directly into a discussion on information warfare and the revolutionary aspects of attacking the source or foundation of an adversary's war making capability. The connecting legs of Clausewitz's "remarkable trinity" --- (1) hate and enmity, (2) the play of probability and chance, and (3) political action--- have gained a fourth phenomenon--- major technological complications. Military, economic, and political power now rest on a

combination of industrial, military, scientific, and administrative competencies.[12] The root source of control of these competencies is information. Information becomes the high ground and the key to stealth's effectiveness. The strong reliance of precision weapons on accurate targeting information, has become the Achilles heel of their effectiveness..

The air attacks in the 1990 Panama operation and the 1991 Persian Gulf war hinted at stealth's effectiveness across a broad range of force levels. During the Panama Operation two F-117 employed precision weapons, targeted against an open field, with the goal of inducing the surrender of a land combat unit. Although the success of this mission is arguable, the concept illustrates the capability to use technology at the low end of the combat spectrum. Air power can be used across the spectrum to apply the appropriate force to an objective of any size, from a single building to a massive army, with minimum risk of domestic political fallout and minimum collateral damage in the target area.[13] The shock effect of the combination of speed plus precision, delivered in an unannounced or undefendable fashion, is equally effective at many levels of conflict.

Stealth allowed the F-117 to operate in a high intensity air defense environment. Before the Iraqis detected it, a massive raid led by F-117 stealth attack aircraft so overwhelmed and largely blinded Iraq's command, control, communications and intelligence (C^3I) that they never recovered the initiative.[14] Stealth became one of key means of Parallel Warfare.

In the future, the ability of the F-117, F-22, and B-2 to achieve operational surprise through stealth will enhance the capability of the U.S. to employ air power as a compellent across the spectrum of conflict.[15] We have not adequately explored the use of stealth across the spectrum of conflict, from a single raid to enhancing the surprise element of our special forces to

increasing the survivability of strategic lift assets. The exploitation of stealth technology has just begun and the U.S. should not be left behind.

History tells us that defeated armies learn the lessons of technology better that the victors. The German development of the Panzer (the tank was invented by the British) and the associated Blitzkrieg doctrine, which made the tank so effective, is one of the many historical examples where the defeated country (Germany in WWI) exploited the technology of the victor (Britain in WWI) and applied it through a revolutionary doctrine. The U.S. reliance on the continued advanced application of technology in warfare tends to help avoid this mistake. It also increases the magnitude of the penalty if the technology is not exploited. If diplomacy and other means have proven inadequate, air power provides a highly sophisticated capability to persuade opponents to alter their political and military behavior.[16] This can be done across a large spectrum of conflict, from the overwhelming force used in Desert Storm to the minimum force required to demonstrate a presence.

Technology Must be Exploited Through Doctrine.

At present, success in a major portion of the contemporary spectrum of warfare is directly derived from technology.[17] Stealth has contributed to the U.S. edge in superior technologies and provides an excellent example of the complex way in which weapons systems, both in perception and reality, have served, or failed to serve, political ends.[18] The results of DESERT STORM highlight stealth's success in this regard. On the other hand, technology's failure to serve political ends results from a number of limitations, but is often the result of inadequate technology exploitation, not in the scientific sense, but in doctrinal application. Improper, irresolute, or unimaginative employment of new technologies have consistently contributed to failed campaigns.

Only the anticipation of future challenges will yield the optimum direction for the doctrinal development and subsequent employment of a given technology.

The B-2

The development of the successor to the venerable B-52, the B-1, started in 1969.[19] In the mid 1960s, Northrop, with vast experience in the development of flying wing designs, had already begun to concentrate on stealth technologies.[20] Northrop's work on the inherently stealthy flying wing design paid off when the company was awarded a contract for 132 B-2 aircraft in 1981, just as the production of the B-1B began.[21] The development of stealth technologies had a broad impact, affecting manufacturing techniques as much as aircraft survivability. The manufacturing tolerances required demanded dramatic changes in the manufacturing process. The system used, a paperless aircraft concept, utilizes Computer Aided Design (CAD) and Computer Integrated Manufacturing (CIM), the use of a single database that can be accessed through a number of widely dispersed company and subcontractor work stations.[22] The flexibility of this system, now the foundation of U.S. military aircraft developers, allows even significant redesigns to be accomplished quickly and efficiently. The need to satisfy the demanding tolerances required in stealth designs motivated a landmark improvement in the way in which aircraft are designed, modified and manufactured. Stealth's contributions to the design and manufacturing process equal or surpass its links to the development of parallel warfare. The success of the CAD/CIM system highlights the breadth of technology's impact on the American way of war.

When it became apparent that the B-2 should have low altitude penetration capability, as a hedge against a counter-stealth breakthrough, it was redesigned in 1984 to enable low altitude

operations. The ability to combine low altitude operations with reduced RCS would enhance and elongate its useful period of effective employment.[23] Even though the CAD/CIM process could accommodate the extensive low altitude redesign, it might have been politically unacceptable, especially if the program had been administered through normal acquisition channels. The black B-2 program allowed a flexibility in the program that was not attainable in a conventional access program where banner headlines, political maneuvering, and bureaucratic infighting would greet any delay announcement.[24] The program time table can be used as a tool instead of a misapplied evaluation metric.[25] The redesign of the B-2 under the auspices of a black program draws attention to the desirability of adapting both the stealth motivated manufacturing processes, already in full swing, and the flexibility inherent in a black program, to the entire acquisition system.

Nothing we have or expect to have will enhance power projection more than the B-2, which can go any where, arrive unannounced, and deliver a powerful blow.[26] The B-2 can be used over enemy territory with some form of gravity weapon again and again. This advantage makes it more affordable and flexible than cruise missiles or battleships, especially when the target is mobile or relocatable.[27] Range, payload, and survivability are the hallmarks of the B-2. Measured in one way, the B-2 generates about ten times the ton-miles of munitions per dollar as the F-117.[28] Its man-in-the-loop flexibility and capability to project global presence with highly survivable firepower makes the B-2 an extremely useful national security tool. Whether demonstrating commitment, executing a show of force, or acting as a U.S. based enabler of parallel warfare, the B-2 weapons system is the epitome of the Air Force motto: *Global Reach -- Global Power*. The B-2 again illustrates the use of technology to improve quality, increasing its

significance with respect to quantity. The procurement of a stealthy bomber force, in adequate numbers, is essential to the global strategic planning requirements of the U.S.[29]

The F-22

Successful implementation of stealth doctrine centers on adequate force numbers and capability, another iteration of the quality quantity mix dilemma. The Skunk Works designed Lockheed's version of the Advanced Tactical Fighter (ATF) in 1988. This design, combined the signature control of an F-117 with the ability to cruise supersonic without using the afterburners and perform combat maneuvering beyond the level ever envisioned in the F-15. The avionics are as powerful as seven Cray computers.[30] However, the "ilities" are what really make the F-22 different than its predecessors. Reliability, maintainability, supportability, maneuverability, distancability (range), haulability (payload), and goability (speed) were the traditional trade-off decisions prior to the late 1970s. Signature control was added at this time and became the main driver in some designs, including the F-117 and the B-2.[31]

It took the jet engine years and numerous iterations before it was developed to the point that it no longer imposed the significant restrictions, that came connected to its advantages, over previous reciprocal propulsion modes. Some observers fix the jet engine's maturity date coincidental with the arrival of the F-15, some thirty-five years after the first jet-powered aircraft had flown.[32] The F-22 achieves the same status with respect to stealth technologies as the F-15 did with respect to jet-engine development. The path to stealth maturity, however, has taken much longer time, slowed by lack of focus, inefficient acquisition system and enabling technologies.

Whereas the F-117 owns the night, the F-22 will own both the night and the day by virtue of its speed, maneuverability, and weapons capabilities. An adequate force to support the employment doctrine will be critical. In the year 2000, 2.5% of the Air Force fighter force will be stealthy (F-117 fleet). If the F-22 buy is completed as scheduled, 22.5% of the force will be stealthy by 2012, assuming that the F-117 remains in the force structure. Adequate numbers of the F-22, employed with an appropriate doctrine during this time period, will be required in order to exploit the U.S. technology advantage. Germany exploited Britain's tank technology and the U.S. exploited Germany's jet technology. The continuous exploitation of stealth technology will be necessary to maintain the overall U.S. technical advantage.

Political Ramifications

The political impact of stealth has not yet been fully exploited. The ability to penetrate highly defended airspace, attack a target with lethal precision, and return with little risk is a military option with significant political implications. Just the threat of such an action could have a significant impact on a targeted government. No lost aircraft, no prisoners, no hostages, and operations under the cover of darkness reduce risk and ease the decision to use such a capability. Night attacks can be both more effective and less dangerous than those performed during the day.[33] Night attack accentuates the psychological effect of defenselessness. When the precision attack itself is followed by the airing of a mission video, focusing on the precise destruction of a selected target with little or no collateral damage, a powerful message of strength and ability to influence events is sent to the viewer.

In some sense the U.S.'s current near monopoly on the application of stealth technologies further supports the concept of "New Warfare." "The New Warfare" has been defined as "the

means by which a nation (or group of nations) seeks to impose its will .... by all means short of total war, and without disturbing its own economy to an extent which is unbearable, or unacceptable, to its people."[34] Stealth enables this approach, but must not be employed simply because it is available. There is an inevitable feedback (link) from forces-in-being, having a capability to react to a particular threat makes it more likely that a response will be made. The existence of the capability may then tend to bias the evaluation of national objectives toward commitment of force.[35] Stealth provided flexibility should not be employed solely because it is available.

Expansion of Deterrence.

The U.S. must expand the concept of deterrence to include a more comprehensive use of air power. This cannot be accomplished without the willingness and ability to severely punish aggressors through air strikes.[36] This exploitation of the U.S. air power card maximizes the key U.S. advantage of stealth-enabled, low risk and highly effective air attacks. The capability to execute these attacks has the potential to greatly constrain the adversary's strategies, particularly those that involve aggressive tendencies.[37] Air power can also affect the fight against the proliferation of weapons of mass destruction. Success in this area requires that the U.S. be prepared to deter the use or potential use of such weapons, defend against them, continue to operate our forces in their presence, and respond to their use. All this must be done in ways that are effective from both the U.S. and adversary's perspective.[38] The abilities of stealth technologies to contribute to this goal have not been adequately tapped. Stealth capabilities provide a broad range of options allowing the selection of the right combination of ability to do the job with an acceptable risk.

Foreign Military Sales Potential.

Although the proliferation of stealth technologies is not currently in the U.S.'s national interest, it will occur. The U.S. has the potential to corner the Foreign Military Sales (FMS) market for stealth derived assets while dramatically improving the capability of our allies to defend themselves. This will be beneficial to both the U.S. and its allies. The future market for stealth derived weapons systems is unknown, but can be expected to grow rapidly as a result of the demonstration of stealth's effectiveness in combat. The time to plan for this process is now. Developing and maintaining the world lead in stealth creates the potential to benefit the U.S. across a wide spectrum. Technology, combined with new applications and proper doctrinal application, has already resulted in dramatically improved U.S. war fighting effectiveness and could lead to security enhancements for both the U.S. and our allies.

The Future of Counterstealth

The U.S. advantages in all-weather, night, and stealth operations, like any technological advantages, will not last. The F-117's DESERT STORM immunity will be degraded over time and adversaries will develop stealth capabilities, forcing the U.S. to focus on counter-stealth measures.[39] Future enemies are learning from Desert Storm and translating lessons learned into countermeasures. "Perhaps the biggest key for the U.S. is to maintain our technological edge."[40] Critical technologies in the 1990s have been identified by various sources. They include sensitive radars (CLO/CVLO), phased arrays, data fusion, passive sensors, fiber optics, micro-electric circuits and signature control (radar, optical acoustic and other).[41] The sheer number of identified disciplines contributing to the development of counterstealth capabilities demonstrate the threat of stealth and the priority attached to the growth of effective countermeasures.

Stealth has not made current radar concepts obsolete, but has certainly challenged its effectiveness. Most ground based radars cannot see beyond the horizon, limiting their range against low-flying targets.[42] Over the horizon radars (OTH), such as the U.S. Paved Paw system, are exceptions to this rule. Space Based Radars (SBR) have range and clutter problems. The long wavelength radars, such as the older Soviet VHF early warning radars, have some capability against stealth technologies, but they are fixed (easy to target), and can't provide the fidelity necessary for a tracking solution (support missile guidance). OTH radars also fall into this category.[43] Bistatic radars are systems where the transmitter and receiver are not collocated.[44] Carrier free radars use a square pulse which reduces the effectiveness of some RAMs.[45] The list goes on and has been reviewed exhaustively in unclassified documents such as the *B-2 Survivability against Air Defense Systems.*[46] Stealth has taken up the lead in the measure - countermeasure cycle, but counter-stealth will proceed, if not by using some of the techniques listed previously, then by others yet to be discovered. Whatever techniques are eventually employed, they probably will not require the development of revolutionary technology, but will be a continuation of the evolution of the effort to degrade the all encompassing reach of radar on the battlefield.

The history of submarine and anti-submarine warfare (ASW) provides a good example of the action-reaction cycle with respect to stealth platforms.[47] Modern nuclear submarines depend almost totally on stealth for survival. Neither the submarine nor the B-2 can be precisely detected, tracked, or engaged at militarily useful ranges in typical operational scenarios. This attribute translates to survivability.[48] Whereas stealth provides survivability, counterstealth or ASW in the case of the submarine, attempts to exploit vulnerabilities. As highlighted in the field

of submarine warfare, U.S. policy wisely strives to develop substantial superiorities in both submarine and ASW capabilities.[49] In pursuit of this goal, the U.S. has consistently invested in both submarine and ASW capabilities.[50] This wise policy applies equally well to stealth and counter-stealth technology development.

Defense against reduced RCS cruise missiles may provide an ever increasing challenge for the U.S. military. Although potential adversaries will probably not approach the U.S.'s stealth design or manufacturing capability in the near future, it should be noted that the reduction of RCS becomes easier the smaller and less complex the platform is.[51] When stealthy capabilities are combined with the easy access of the U.S. provided Global Positioning System (GPS), the threat posed by potential enemies may increase rapidly.[52] We must position ourselves to defend against such capabilities by securing and deploying counterstealth systems.

A counter-stealth fighter could be deployed in much the same way as the first significant operational stealth capability, the F-117. Just as the F-117 included signature control as a high priority goal in the F-117 design trade-off process, a counter-stealth capability would be assigned a high priority in a counter-stealth design. The counter-stealth platform would probably sacrifice some maneuverability for the weight penalty that a counter-stealth radar would likely have, just as the F-117 traded off maneuverability for stealth. Relatively small numbers could be acquired and deployed, emulating the small quantity/high quality mix decision driven by the F-117 (stealth) mission requirements. These small numbers would be routinely based on the U.S. mainland to provide air defense against stealthy aircraft and cruise missiles, but could deploy to support a regional Commander-in-Chief (CINC), if required.

The F-15 is a good candidate for the counter-stealth mission. Due to the ongoing force structure reductions, a quantity of F-15 airframes are available. The F-15 is the most likely fighter to be able to provide the antenna area, power, cooling, and airframe compatibility with a powerful counter-stealth radar. Modifying two squadrons of aircraft and deploying them to both coasts, to the sites of the current Air National Guard (ANG) F-15 air defense squadrons, would enhance the current air defense mission, cause no increase in force structure, and provide the U.S. with an effective counterstealth capability. Maintenance experience levels resident in the ANG would provide the capability to maintain a unique avionics suite while minimizing configuration diversity in the active duty fleet. The lessons learned in such a program would become the baseline for future counter-stealth technology developments while putting a near term counterstealth capability in place. The U.S. would not forfeit the lead in counterstealth technologies much as it has not relinquished the lead in ASW.

Other Perspectives

The Russian perspective of stealth and counter-stealth may be quite different than that of the U.S. Interestingly enough, the Russians appear to have little interest in stealth technologies. Perhaps they are not motivated because the U.S. has such a limited IADS. However we should not be quick to conclude that little interest in stealth translates to little interest in counter-stealth. The Russians, "losers" in the Gulf war in the sense that they supplied the equipment, training, and tactics to the Iraqis, have seen a clear demonstration of what the future holds. At the same time other countries have also witnessed the success of precision ordnance delivered by stealth platforms during Desert Storm.

The synergistic combination of stealth and precision, illustrated by the F-117 in the Gulf, makes it difficult to the specific contribution of each. Most military theory at the tactical level predates precision weaponry. The high probability of successful target engagement provided by precision weapons can create important changes at the operational and strategic levels of conflict, parallel warfare.[53] The reduction in risk of the employment of precision weapons, afforded by stealth, will send other countries traveling down the path of stealth development and employment. Just as the Germans were motivated to develop the Blitzkrieg after WWI, Russia and other countries can be expected to focus on the development of counter stealth capabilities. The ability of a country, currently limited to the U.S., to cause extreme conventional damage to a selected target anywhere in the world with little risk, is a powerful incentive to search out effective counters.

The U.S., in fact, had set up a Counter-stealth office in the Pentagon as early as January 1977, initially to try to predict the capability of other countries to counter stealth in a specific time frame. A consensus of those that have studied the problem in the U.S. is that counter-stealth technology is one hundred times more difficult to develop than the original stealth capability. It would require extraordinary super computer breakthroughs, an area where the Russians were least developed and least likely to succeed.[54] This information contributed to the ongoing stealth cost-benefit assessment. Would the longevity of stealth's dominance be worth its cost of development and associated security expenses? The resulting cost benefit analysis explored the probability of the development of counterstealth capabilities in various time frames and ultimately concluded that the investment was worthwhile.[55]

Window of Dominance - Stealth Gap

How long the U.S. will maintain its dominance in stealth is a matter of speculation. Past periods or windows of dominance have sometimes been identified as "gaps." Many subscribe to the theory of gapology. First there was a bomber gap and then a missile gap. These two gaps, each emphasizing a then current Soviet advantage, may not have been real, but they were at least perceived. The U.S. could be said to have enjoyed the positive side of a fifteen year air superiority gap following the introduction of the F-15 in 1976 and is currently in the midst of a stealth gap, exploited during DESERT STORM. The number of years that the stealth gap, or any advantage, will remain in force is unknown. The fact that it will be bridged is certain. Schemers never sleep and there are always counters to every new technology.[56] The U.S. must not only continue to improve and develop stealth technology and doctrine, but build on its counterstealth foundation. The likelihood is very high that many countries will not immediately focus on their defensive requirements, counterstealth, but instead emphasize the development of offensive stealth vehicles.

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CHAPTER 8 -- Conclusion

The American way of war has become dependent on the development and application of technology. Stealth is a good example of one of those technologies. However, the technology development process that supports the American way of war has not achieved the same level of success as the machine it supports. The guiding doctrine required as the input to the technology selection process has become increasingly mired in bureaucracy which has only occasionally been overcome. Stealth's success in Desert Storm has tended to obscure the mounting challenges to developing breakthrough type technologies in the current acquisition system. The human element has not diminished, but become more important in the administration of the technology development process. Stealth is a great American success story. It must be exploited and further developed if the U.S. is going to continue to produce technology advances required to support the American way of war.

The Technology Lead is Critical

While the U.S. must not relinquish its stealth lead, it must carefully develop the counterstealth capabilities that will be necessary to defend against the stealth threat that will eventually appear. Chief Justice Holmes once said, "to rest upon a certainty is a slumber which, if prolonged, brings death."[1] The U.S. must not rest on its laurels. "Sustaining Global Reach--Global Power depends on pursuing the innovative technologies and concepts of operations that offer the highest pay-off in capability."[2] Stealth is one of these technologies, but it, like all technologies, depends on the acquisition system that supports it.

The U.S. must maintain the kind of streamlined approach to acquisition that is enabled by black program management The Skunk Works and the F-117 pioneered many of these techniques.[3] Current Secretary of Defense William J. Perry has emphasized the type of organization required for success in recent comments, "A small research and development operation that relies on close-knit, can-do, highly technical groups working on advanced and complex problems. They are self contained, do not require many people or big budgets."[4] The structure of the organization that produces the technology is as important as the one that employs it.

The Inadequacy of the Technology Selection Process

The value of stealth is an overarching lesson of the Gulf air war. No other country is likely to catch up---unless we give the lead away. No one else can currently manufacture it or defend against it.[5] Fortunately for us, duplication of the technology, organization, theory, and training that brought us one of the great military victories of history is terribly expensive. This capability requires such an extraordinarily broad scientific, military, and industrial base that it may take two decades for another country or countries to develop similar offensive capabilities or construct effective defenses.[6] However, the analytical and design capabilities, inherent in the system that produced the F-117, were the products of America's commitment to technology development. That commitment, the result of many decades of continuous intellectual tradition and governmental support, could not be reconstituted in real time if it were allowed to dissolve or decay gradually.[7] This part of the system has passed the test, but the system that selects the technologies for development does not measure up to the same standards. While the current acquisition system may make good sense in an environment that relies on incremental technical

changes, it badly needs attention in periods of decreasing budgets and security uncertainties. A system that puts top premium on breakthrough technologies and dominating advances is necessary. The internal budget process is not the right place to resolve doctrinal issues. Those issues need to be resolved outside of the budget system and then applied as an input, providing the overall guidance necessary to the efficient operation of the acquisition system. To date only black programs have made substantial gains in this arena. Conversely, no such successful demonstration has been made under an acquisition system dominated by multiple and diverse inputs.[8]

Technology's Human Nature

At the conclusion of WWII, the advent of the atomic bomb added superior technology to diplomacy as equal contributors to an equation that previously relied primarily on the organization and mass of military forces to prevent war or conduct effective military operations. Technology's influence on the expansion of the range of military operations to a global scale and the associated increase in casualties in noncombatant and nondeployed military forces, including all of their support infrastructure, further had the effect of humanizing war as much as it dehumanized conflict. Wider human participation, desired or not, tends to enhance Clausewitz's vision of the human nature of war.[9] The history of the development and employment of stealth technologies is not just a tale of technology, but also of the ever expanding importance of the human element of conflict. This human element is increasingly focused on the technology selection, development, production and application process although it continues to remain active in the combat field as well. Stealth has even turned back the clock on the "manned aircraft are on the way out" prediction that has been resurrected with each new technological advance.

The application of new technologies, yielding important military advantages, has been generally applied in the context of universally held national social and cultural beliefs. It follows that the evaluation process of such technologies, including their adoption or rejection, is also influenced by these overarching ideas.[10] Technology's distinct place in the American national culture should continue to be recognized and exploited. The history of U.S. technological development, including cultural and governmental influences, can produce valuable lessons relating to the development of an improved system. The process by which technology is derived, developed, tested, implemented and applied does not change much over time, both in the short and long term. This fact makes history all the more relevant to our technology process insights and challenges.[11] Technology selection decisions for major weapons used during Desert Storm were made at least two decades earlier. People made these choices in spite of turbulence and criticism and their choices were vindicated during the war.[12] Many predict that significant advances in stealth capability may yet be achieved across a large spectrum of warfare.[13] The U.S. must leverage history to take advantage of this prediction by guiding the modification of the process from that of the current cost benefit analysis to a dynamic innovative source of technology leadership for the twenty-first century.

The English dealt the French a crushing blow at Crecy, France in 1346, making use of the defensive advantage, terrain, a secret weapon, and the skilled use of combined arms. Applied doctrine carried the day, along with the judicious use of stand-off weapons. Although the longbow had been around for over two hundred years, it had not been exploited in battle. The use of the cannon, during its first employment in the West, went almost unnoticed. Stealth, like

the longbow, has come into its own after an extended development period. Hopefully counterstealth technologies will not follow the unnoticed debut of the cannon.

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